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12

**WEAPON SYSTEM COSTING METHODOLOGY
FOR AIRCRAFT AIRFRAMES
AND BASIC STRUCTURES
Volume I • Technical Volume**

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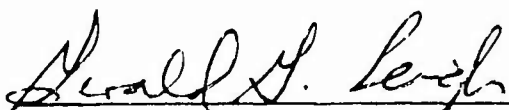
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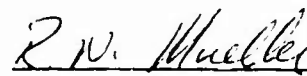
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FOR THE COMMANDER


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jected cost of a complete airframe within the context of a weapon system development. This volume provides a technical discussion of method development.

Tradeoff capability has been provided for a range of alternative structure and material combinations. A technique for independently assessing complexity factors has been developed and demonstrated. Manufacturing costs are separately estimated for the primary elements of substructure: ribs, spars, covers, leading edges, trailing edges, tips, etc. The trade study method provides an iterative capability stemming from a direct interface with design synthesis programs. A detailed cost data base and system for data expansion is provided. The methods are designed for ease in changing cost estimating relationships and estimating coefficients resulting from cost data update.

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FOREWORD

This report was prepared by the Convair Division of General Dynamics, San Diego, California, under USAF Contract F33615-73 C-2083. The contract, titled "Weapon System Costing Methodology for Aircraft Airframes and Basic Structures," was initiated under Project 1368, "Advanced Structures for Military Aerospace Vehicles," Task 136802, "Structural Integration for Military Aerospace Vehicles."

The work was administered under the direction of the Air Force Flight Dynamics Laboratory, Structures Division, Wright-Patterson Air Force Base, Ohio, under the direction of Mr. R. N. Mueller (AFFDL/FBR) as Project Engineer.

This report covers work conducted from July 1972 to March 1975 and was submitted by the author in April 1975, under Air Force Flight Dynamics Laboratory Report No. TR-75-44 as a Final Report. This report includes one additional volume: Volume II, Estimating Handbook and User's Manual.

The principal author and project leader on this program is Mr. R. E. Kenyon, under the administration of Mr. G. E. Vail, Chief of Economic Analysis and Mr. A. Van Duren, Manager of Operations Research. Others who contributed to the studies and who contributed in the preparation of this volume include Messrs. J. L. Youngs, Economic Analysis; B. H. Oman and W. D. Honeycutt, Mass Properties; L. M. Peterson and G. S. Kruse, Structural Analysis; G. G. Clark, Analytical Programming; and T. Kell, Industrial Engineering. The material in Appendix D, in particular was authored by B. H. Oman and W. D. Honeycutt.

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SECTION I

INTRODUCTION

This report describes a study to develop preliminary design level techniques for estimating the cost of flight vehicle structure in a way that provides sensitivity to the type of construction and the type of material used. Two techniques, or capabilities, are involved:

- a. The ability to estimate costs of different airframe structures at a level of detail to support tradeoff studies involved in the structural design process.
- b. The ability to estimate total airframe costs, including basic structure and functional subsystems, to support the evaluation of proposed systems in a system study context.

The first estimating method produces what is referred to in this study as trade study costs. This method requires the development of a technique that allows the designer to compare competing designs on a relative cost basis where the relative cost of each design is accurately represented, and the inputs required for cost estimating are within the data base normally generated during preliminary design. The second method produces what is referred to as system study costs. It requires the development of a technique that is also sensitive to design concepts and materials and that supports estimating on an absolute cost basis for inclusion in system concepts studies.

The current effort is an extension of the development under a previous Air Force contract and documented in Reference 1. That contract resulted in a methodology for airframe structural cost estimation and the demonstration of the method based on horizontal stabilizer examples. The extension of the method encompassed the remaining major items of the airframe basic structure; i.e., vertical tail, wing, fuselage, landing gear, and air induction/nacelle. This report covers that effort and is a continuation of the reporting covered by the contract Interim Report, Reference 2.

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1. R. E. Kenyon, "Techniques for Estimating Weapon System Structural Costs," AFFDL-TR-71-74, Final Report (Contract F33615-70-C-1340), April, 1972.
 2. R. E. Kenyon, "Weapon System Costing Methodology for Aircraft Airframes and Basic Structures," AFFDL-TR-73-129, Volumes 1 through 4, Interim Report (Contract F33615-72-C-2083), December, 1973.

These estimating methods are needed to meet the requirements of the present day weapons system acquisition process. Most of the key decisions affecting the cost of the weapon system are made early in the design process, during concept formulation. Decisions regarding the application of new technologies must be made during this phase if they are to be introduced to the new weapons systems. This gives rise to a need to assess during preliminary design the impact on cost of alternative designs. This creates a cost analysis problem since existing estimating methods have deficiencies when required to operate in the environment of early preliminary design. The cost analysis problems include such items as: (1) lack of sensitivity to structural considerations, i.e., type of construction and material; (2) lack of integration with design and producibility considerations; (3) lack of a sufficiently detailed analysis to support structural tradeoff studies; (4) limitations on product definition and input data inherent in that stage of program development; and (5) the continuing need for accuracy in cost estimates.

As the number of materials and structural design concepts applicable to flight vehicle increases, it becomes increasingly important to know the detailed relative costs of equal performance designs so that the impact of design options can be assessed. Past experience and a review of available literature describing current estimating methods reveal major deficiencies in these methods with respect to: (1) oversimplification of cost models and the lack of depth of analysis required to evaluate cost sensitivity to design tradeoff choices in terms of construction methods and structural material; (2) over-reliance on weight estimates as a single cost-driving variable and especially ignoring the discontinuity in the cost-weight relationship brought about by the advent of increasingly exotic materials and fabrication complexities that can create an inverse cost-weight relationship; and (3) a lack of integration of design methods and costing procedures to provide a timely feedback to designers to influence cost-oriented design decisions. Each of these shortcomings has contributed to the cost estimator's difficulties in responding to the requirements for costing new airframe designs and for providing inputs to the designer in a design tradeoff process. This has given rise to the need for defining a new type of estimating process.

1.1 STUDY OBJECTIVES

The specific objectives of this phase of the study were:

- a. To extend the trade study costing method to the remaining elements of the basic structure: the fuselage, nacelles, and landing gear.
- b. To provide a computerized cost model for estimating basic structure hardware elements, nonrecurring, first unit, and recurring costs.

- c. To complete the development of the system cost estimating method for the complete airframe.
- d. To complete ancillary studies dealing with finite element synthesis applicability, preliminary design applications, interactive graphics applications, computer program integration, and operating cost interrelationships.
- e. To provide means of updating the methodology to consider advanced structures and composite materials.
- f. To provide computer programs for installation of the system at the Air Force Flight Dynamics Laboratory.
- g. To select a test case and perform a demonstration estimate in order to debug the computer program, to verify the estimating logic and to provide for coordination of the system installation.
- h. To document and present the methodology as contractually required.

1.2 SCOPE AND LIMITATIONS

The study was limited to a subset of cost categories defined from the total set of weapon system cost categories. The categories considered included nonrecurring design and development, recurring design and development, and recurring production. These were defined, from a work breakdown structure standpoint, as including basic structure only in the case of the trade study method and airframe only, i.e., basic structure plus functional subsystems, in the case of the system study method. This excludes costs such as avionics, propulsion, and other costs identified to the weapon system, such as support costs, or identified to the total vehicle, such as aircraft flight tests.

In addition to the different areas of cost covered by each method, different levels of detail are also involved. The trade study method deals with the subassembly level whereas the system method deals with the aircraft subsystem level. However, this distinction applies only to manufacturing costs. Nonrecurring costs are handled at the same level in both methods, and in fact, some of the same cost estimating relationships are used.

Primary emphasis has been given to the trade study cost method, inasmuch as the principal objective of the study is to support tradeoff studies in system design to answer specific questions regarding selection of type of material and construction. Tradeoff capability has been provided for a range of alternative structure and material combinations based on the present analytical capability of the multistation structural synthesis and other synthesis programs used. These combinations are

first categorized by basic aircraft structural concepts: skin stringer or multirib type applicable to a wide range of aircraft having moderate speed and load factor requirements; multispar structure that characterizes the high-speed high-load factor; and full-depth sandwich, which is usually confined to very thin surfaces such as tails. The primary elements of substructure, that is, ribs, spars, and covers, are further categorized by basic types of construction.

The trade study cost method uses weight and dimensional data obtained from a supporting synthesis program as the primary cost-related variables in the cost estimating relationships. A structural synthesis program provides stress and dimensional analyses of structural components and weight data in accordance with input choices of type of structure and material and provides the basis for interrelating the results of these analyses with cost. The structural synthesis program is in turn driven by a vehicle synthesis program, with the result that a preliminary design study loop can be operated to evaluate the impact of airframe configuration changes generated by variations in performance requirements. Development of these synthesis programs is not part of this study.

The study has been limited to the contractor's own cost data, and furthermore, the study has carried forward the idea of two different time frames with respect to the availability of cost data. This concept of availability is referred to as limited data and unlimited data availability. Limited data is that which is reasonably available at the present time. Unlimited data is that which can reasonably be made available in a future time period, using more extensive methods of data collection.

A limited literature survey of specific references has been accomplished during these studies to investigate representative estimating approaches as an aid in developing cost estimating relationship forms. This survey has been augmented by continuing Convair Division research programs to develop unique methods for estimating cost tradeoff penalties and payoffs. This research has been devoted to (1) identifying cost-related variables, (2) development of structural and weight analysis tools, and (3) developing the groundwork for the application of these tools to the analysis of costs. Results of this survey were described in References 1 and 2.

Estimating techniques are expected to be updated by incorporation of new materials and concepts, labor and material price changes, an expanded treatment of composite materials, and the impact of new aerodynamics on construction methods. So that, although the method is not yet fully developed, it provides a sound basis for systematic enlargement to provide the analyst with the detailed insights for effective cost analysis and the basis for future expansion of the data base.

1.3 BACKGROUND

The present contract is a follow-on to Air Force Contract F33615-70-C-1340 spon-

sored by the Structures Division of the Flight Dynamics Laboratory. That study provided for the investigation of representative approaches to cost estimating as they are described in the available literature, the conception and evaluation of new approaches, the final selection of an approach for each of the two required types of estimating, and the development of the selected approaches to the point that their feasibility could be demonstrated.

The feasibility study was followed by a second contract, which is the current study. It provides for extending the trade study cost estimating techniques from the horizontal stabilizer to the entire basic structure. The results and findings of the first phase are being combined with the results of the additional research and study to produce an expanded and updated estimating system. The initial estimating techniques were demonstrated using the horizontal stabilizer for evaluation purposes. Additional test cases were run, based on all elements of the aerodynamic surfaces, the fuselage and nacelle components and a final demonstration based on all elements of a single aircraft.

1.4 ORGANIZATION OF THE REPORT

The Final Report is presented in two volumes: Volume I, which is this volume, the Technical Volume, and Volume II, Parts I and II, which make up the Estimating Handbook and User's Manual. The Estimating Handbook and User's Manual (referred to as the Estimating Handbook) provides a detailed description of the function and use of the two costing methodologies. It answers the question: How to make an estimate using these methods? It describes the costing output, the cost estimating relationships, the detailed inputs required, and the processes for developing these inputs. It also describes the cost model computer program interface with the supporting synthesis programs and the interrelationship between baseline costing factors and the historical cost data base. The development of complexity factors used in the estimating process is also described in detail. The inputs and outputs of a demonstration case, using the B-58 aircraft, are also described. This volume describes the estimating process in its entirety in conceptual terms and reports the cost research and development accomplished subsequent to the interim report, consisting of the development of the fuselage - nacelle - landing gear modules, the system cost estimating method, the cost model computer program, the installation of the cost estimating system, other related studies, and the method demonstration.

Each of the estimating methods is covered separately: the trade study method in Section II and the system method in Section III. The cost model computer program for both methods is described as a separate topic in Section IV. Design synthesis and weight analysis supporting programs relate only to the trade study method and are discussed in Section V. The method demonstration encompasses both methods and is covered in Section VI. Section VII describes ancillary studies not discussed elsewhere.

1.5 WHY TWO METHODS?

Both estimating methods are used during preliminary design at an earlier stage than is normally associated with traditional estimating method. Although the primary interest in the study lies in the capability to do detailed trade studies provided by the trade study method, the system cost estimating method provides additional capability in the following manner:

- a. It permits an earlier initiation of estimating effort since it responds to a more limited predesign activity, functioning with a much more limited input data availability.
- b. It provides a more inclusive set of cost estimates covering the total airframe and permitting comparisons and evaluation in a specific frame of reference.
- c. It is based on a larger historical data base with the attendant possibility of improved estimating accuracy.
- d. It provides a systematic transition to trade study costing through a dual mode of operation that involves substitution of detailed estimates by hardware element in a progression as input data becomes available.

The combination of capabilities provides earlier cost estimating results and a selective process for introducing detailed estimating. Discussion of the preliminary design environment in which each of the two methods might be expected to function is handled in the related sections.

SECTION II

TRADE STUDY COST ESTIMATING METHOD

This section of the report gives a brief review of previously reported activity, discusses and describes the estimating method that has resulted from the study, gives a report on the trade study related activity since the interim report (primarily the development of the fuselage estimating module), and finally describes the expected, or possible, future development of the method.

2.1 REVIEW OF PREVIOUS ACTIVITY

This is a brief review of activity occurring during the initial feasibility study under Contract F33615-70-C-1340 and the activity under the current contract involved in developing the estimating module for aerodynamic surfaces and described in the interim report.

The objective of the initial study was to develop a basic trade study cost estimating methodology and to demonstrate its feasibility using a selected structural component: the horizontal stabilizer.

The study included the investigation of representative approaches to cost estimating as they are described in the available literature, the conception and evaluation of new approaches, the final selection of an approach for estimating, and the development of the selected approach to the point that its suitability could be demonstrated. The method developed was eclectic in that it combined elements of each of the basic estimating methods that could be categorized from the literature, e.g., the industrial engineering approach, statistical estimation, and estimating by analogs.

A concept of first unit cost was introduced at the airframe level as a means of estimating hardware manufacturing costs. The term airframe was defined differently for trade costing and system study costing. In the case of trade costs, airframe means the traditional vehicle basic structure, excluding subsystems. In the case of system study costs it is defined to mean empty weight minus propulsion and avionics.

A limited literature survey of specific references was accomplished to investigate representative estimating approaches as an aid in developing cost estimating relationship forms. This survey was augmented by continuing Convair Division research programs to develop unique methods for estimating cost tradeoff penalties and pay-offs. This research has been devoted to identifying cost-driving variables, to the development of structural and weight analysis tools, and to laying the groundwork for the application of these analytical tools to the analysis of costs.

The trade cost method was developed to use weight, part count, and dimensional data, obtained from a multistation structural synthesis program, as the primary cost related variables in its cost estimating relationships. The study selected for development an estimating methodology and specific cost estimating relationships that used synthesis program outputs. The structural synthesis program provides stress and dimensional analyses of structural components and weights data in accordance with input choices of type of structure and material and provides the basis for interrelating the results of these analyses with cost. The structural synthesis program can be in turn driven by a vehicle synthesis program with the result that a preliminary design study loop can be operated to evaluate the impact of airframe configuration changes generated by variations in performance requirements.

The study approach and results are completely described in Reference 1. That report describes the study of available techniques, the selection of suitable approaches, and the range of cost categories estimated. Schematics of the recommended estimating technique are shown. The types of aircraft, candidate structural concepts, and feasible material combinations are also described. Collection of cost data, derivation of cost estimating relationships (CERs), the interface with the structural synthesis program, the procedures for estimating special construction features and composite material application, the demonstration of the technique with the horizontal stabilizer structural element, and the proposed extension of the method to the remainder of the aircraft structure are all discussed. Appendices are included to augment the description of method, to describe the data used in the demonstration cases, and to provide additional backup data for the justification and explanation of demonstration input values.

The activity covered by the interim report had as its general objective the extension of the methodology to the hardware elements comprising the aerodynamic surfaces. The specific objectives of the study were (1) extension of the trade study method to the vertical stabilizer, canards and wings, (2) initiation of the extension of the method for fuselages, nacelles, and landing gear, (3) initiation of an updating of the method to consider advanced structures and composite materials, and (4) providing a computerized module for aerodynamic surfaces to be compatible with the final cost model and to interface with supporting structural synthesis and weight estimating programs. The accomplishment with respect to this phase of the study is described in Reference 2, the Interim Report.

This report was presented in four volumes. Volume 1 provided a discussion of cost methods research and development. Volume 2 described the development and integration of supporting programs: multistation structural synthesis programs, secondary structure synthesis, and weight estimating methods. Volume 3 presented the cost and technical data used in the development and verification of the cost methods, and included cost trend data representing various summaries of cost made

available as a basis for system cost level comparisons. Volume 4 consisted of an estimating techniques handbook for the estimating method and a user's guide to the computerized programs.

2.2 TECHNICAL DISCUSSION AND METHOD DESCRIPTION

This section provides a description and technical discussion of the trade study cost estimating method. The preliminary design situation in which the model would find application is described. Some salient considerations in the development are discussed, and an overview description of the method is presented. This leads to a discussion of the derivation of the basic cost estimating relationships used in the estimating process.

2.2.1 PRELIMINARY DESIGN APPLICATIONS. Both the trade study and system cost estimating methods are intended for use during preliminary design. They are combined in a single computer program so that different operational modes are available for application to various estimating problems. The modes are:

- a. The trade study method operating alone.
- b. The system costing method operating alone.
- c. Both methods operating simultaneously providing two separate estimates.
- d. The system costing method operating as the dominant mode but substituting trade study estimates for individual hardware elements to provide more detailed estimates for those elements.

It has generally been the Air Force's experience that most of the decisions affecting the cost of a new weapon system are made during the conceptual design phase. It is stated in Reference 3 " . . . that as many as 75% of the decisions effecting the acquisition cost are made at a point in time when a very small percentage of the total development funds, only about 2%, are expended. "

Identification of this problem led to the initiation of this study with the need for using cost as a design parameter identified. More recently, DoD has evolved the Design-to-Cost approach for weapon system acquisition, which has emphasized the need for cost models that operate from design characteristics.

3. M. E. Talley and R. N. Mueller, "Rationale For Cost-Weight Analysis," AIAA Paper No. 74-961, AIAA 6th Aircraft Design, Flight Test and Operations Meeting, Los Angeles, Calif., August 12-14, 1974.

Use of cost as a design parameter requires a cost estimating process that is different from traditional processes. By means of their iterative capability, their sensitivity to material and type of construction, their computerization to provide rapid response, their interface with design synthesis programs, their detailed costing format, and their flexibility in terms of mode of operation, the methods outlined represent a significant step in the development of design-to-cost methodology.

Use of this estimating approach involves a prescribed interface between predesign and cost analysis activity. This is illustrated in Figure 1. The two activities of design and vehicle sizing, shown as dotted blocks, were not addressed in this study. They are, however, a necessary source of inputs to the supporting structural and weight synthesis programs, which have been included. The interface between the cost analysis and the synthesis programs is fully described, including operational worksheets, in Section 2.2.2.4. A very significant part of the design-to-cost requirement is that the results of the cost analysis be taken into account in the design even to the extent of it becoming a possible redesign requirement.

The estimating method is currently operational. Major applications currently foreseen are as follows:

- a. Use of the trade study method in the evaluation of new types of construction and materials as part of an advanced development responsibility requiring the evaluation of new technologies.
- b. Use of the trade study method in the performance of design trade-offs in the furtherance of design-to-cost objectives and other designated trade-off studies.
- c. Use of both methods to develop comparative cost data for the evaluation of proposed new system concepts.
- d. Use of the system costing method in the early phases of design when complete design information is lacking and when only a subsystem level of detail is required.

The first of these applications is accomplished as a part of an advanced development program and is largely independent of the schedules for specific weapon system development. It is concerned with evaluating the choices to be made in selecting from among new structural concepts. It provides the basis for advancement in technology while considering the cost impact. Future advanced development programs are candidates for this type of cost analysis.

The use of the trade study method for design-to-cost involves structural design trades as a part of the larger task of system design trades. Structural design trades

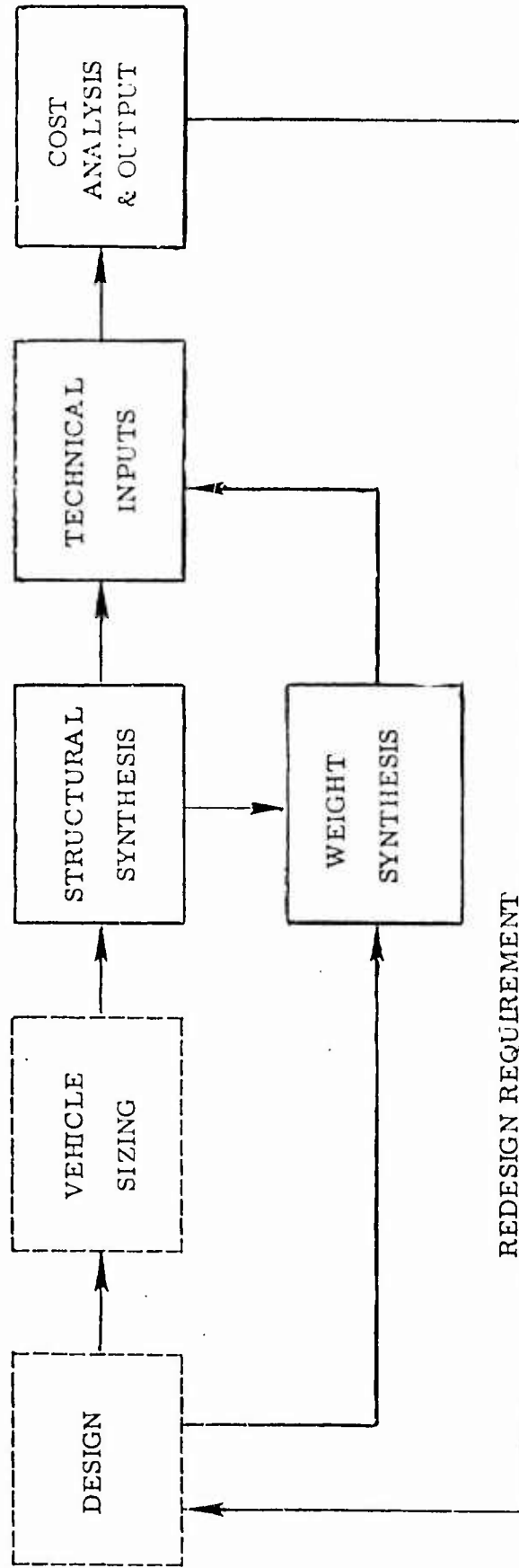


Figure 1. Predesign-Cost Analysis Interface.

are also performed in connection with producibility trades. The level of analysis tends to be progressively more detailed as the program progresses. These evaluations support the use of cost as a design parameter, measuring the impact on cost of alternative concepts.

The development of comparative cost data for use in evaluating proposed new system concepts involves either the joint use (mode d.) of the two methods or the use of the system costing method alone. The use of both methods is a complex solution since the necessary supporting synthesis programs and design activity must be called into play. The system method used alone requires substantially fewer inputs but does not provide a detailed cost breakdown.

The system costing method can be resorted to in the early phases of costing when design trades are not involved but when point designs need to be costed. The trade study method by itself answers questions as to the relative costs of different design approaches to support trade studies, but these data do not account for all airframe system costs and cannot therefore be compared to system level costs. With the methods used in combination, both types of costing can be accomplished.

2.2.2 METHOD DEVELOPMENT CONSIDERATIONS. Development of the trade study cost estimating method involved issues that are briefly reviewed in this section.

2.2.2.1 Costs To Be Estimated. Throughout the study, it has been necessary to specify the boundaries for the costs being estimated. This was necessary with respect to the delineation of cost categories to be covered and to definitions for the categories that were included. Identification of the subset of costs to be dealt with with respect to total weapon system costs were described in Reference 1. The major cost categories of RDT&E, Investment, and Operating Costs were defined. Operating costs were later excluded from quantitative consideration. The resulting categories were:

Cost Categories Studied		
	<u>RDT&E</u>	<u>Investment</u>
Nonrecurring Design and Development:		
Engineering - Design & Design Support	X	
Tooling - Initial and Rate	X	
Manufacturing Labor	X	
Material: RDT&E and Vendor Support	X	

Cost Categories Studied (Continued)

	<u>RDT&E</u>	<u>Investment</u>
Recurring Airframe Production:		
Mfg. First Unit		
Test Hardware	X	
Sustaining Engineering	X	X
Sustaining Tooling	X	X
Production Hardware		X

A definition of cost categories has been accomplished with respect to the cost estimating output format described in Section 2.2.3. These definitions are given in Appendix B, following the listing of CER forms in Appendix A.

Manufacturing first unit cost is used as an estimating device for obtaining the first article cost of a production series.

2.2.2.2 Level of Detail. The level of detail to be used in the trade study cost estimating method was an issue in its development. This comes about in relation to cost data availability, the level necessary to perform significant trade studies, the rationale of the cost estimating logic, and the resulting input requirements.

As it developed, the most significant criterion was determined to be the level of detail necessary for adequate trade study. Design choices relating to structure are defined with respect to type of construction, which is in the main determined by the structural synthesis program level of analysis. The exception is secondary structure, which is less rigorously defined. But more importantly, the substitution of parts and the consequent definition of an element of hardware need to be accomplished at the relatively low level of detail consisting of ribs, spars, etc. There are arguments for an even lower level of substitution, but these must be measured against another significant criterion, the level of cost data availability.

In the case of cost data availability, level of detail is used as a determinant in defining limited and unlimited data. Data is not readily available at the level specified for the trade study method. Special studies were required for the data acquired, putting it in the category of unlimited data. However, this level of cost data collection is considered desirable for future efforts, and existing formats are intended for use in directing such effort.

The development of cost estimating relationships was not determined to be constrained by level of detail since relationships can be established at various levels, i.e., subsystem, subassembly, or detail part. This is verified by the existence of such relationships at each of these levels.

input requirements, of course, derive from the estimating relationships and in general become greater at a lower level of detail. The selection of level for the trade study method was not constrained by this, however, for the reasons that (1) input availability can be matched by virtue of having both the trade study and system cost models and (2) computerization, including interface with the computerized, supporting synthesis models facilitates the handling of inputs.

2.2.2.3 Cost Data Availability. The question of cost data availability was stated in terms of "limited data availability" and "unlimited data availability." The first term is intended to mean data as it is currently available, primarily in terms of the hardware level to which it is broken out. The second term applies to the notion of improving the breakout and availability of cost data by future, more comprehensive, cost data collection approaches. Obviously, limits apply to the later situation, but relative to current availability, it represents a substantial increase in cost data availability.

A further study limitation was that only the contractor's own data would be used. A summary of the raw cost data that was developed on an aircraft basis is shown in Figure 2. Processing and analysis of this data resulted in a raw data bank consisting of three elements as shown in Figure 3.

C-141A	HORIZONTAL AND VERTICAL STABILIZER
C-5A	HORIZONTAL AND VERTICAL STABILIZER
F-111A	CONVENTIONAL HORIZONTAL STABILIZER
F-111A	EXPERIMENTAL BORON HORIZONTAL STABILIZER
F-111A	VERTICAL FIN, WING, FUSELAGE, LANDING GEAR
VSN	PROPOSED S-3A CONFIGURATION, SUBSYSTEM LEVEL
AX	PROPOSED CONFIGURATION, SUBSYSTEM LEVEL
VFX	PROPOSED F-14 CONFIGURATION, SUBSYSTEM LEVEL
B-52	OUTER WING PANELS
880/990	HORIZONTAL STABILIZER, WING, FUSELAGE, NACELLES
LIT	PROPOSED CONFIGURATIONS, SUBSYSTEM LEVEL
MODEL 48	CHARGER PROTOTYPE AIRCRAFT, AIRFRAME TOTAL
F-102A	AIRCRAFT PROGRAM, AIRFRAME TOTAL
F-106A	AIRCRAFT PROGRAM, AIRFRAME TOTAL
B-58	AIRCRAFT PROGRAM, SUBSYSTEM LEVEL

Figure 2. Total Aircraft Sample.

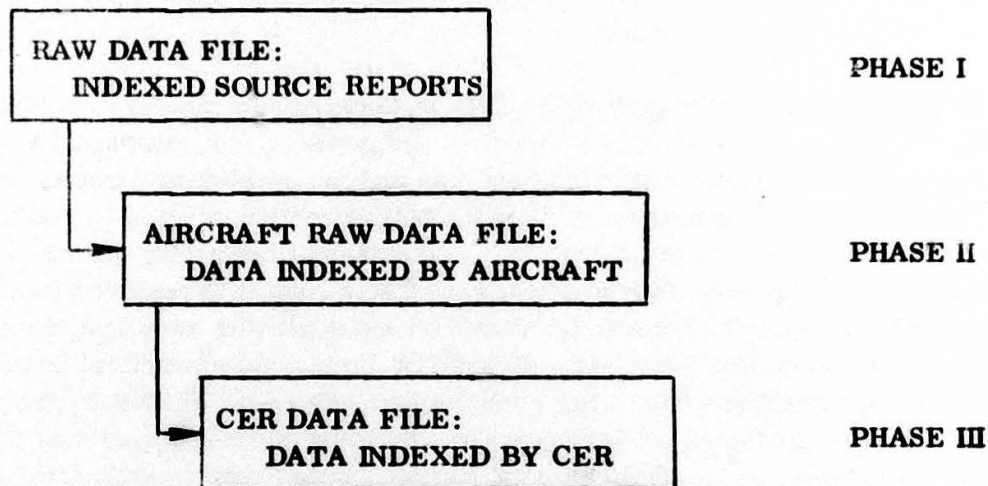


Figure 3. Cost Data Bank Organization.

The ultimate objective of the processing and analysis of the cost data is to provide CER back-up data. This data phase is entered in Volume II of the report and cross-referenced to the applicable CER.

The data available from accounting records has been augmented by data from proposal estimates, by special analyses of the actual cost data, and by special cost studies. The use of proposal data is felt to be warranted because of the small sample sizes that result at the level of detail undertaken. Special analyses of cost data are described in several places in Reference 1. Data from special studies is described in Volume II of this report. It consists of industrial engineering studies based on the analysis of manufacturing processes involved with relevant types of construction and types of material and based on results from various experimental hardware projects.

2.2.2.4 Interface With Design Synthesis Programs. As shown in Figure 1, technical inputs are supplied to the cost analysis process by the various design synthesis programs involved. The operation of these programs to supply the required inputs is crucial to the iterative operation of the cost model. The transfer of data between the cost model and its supporting programs is handled manually. A series of worksheets have been devised to handle the input/output sets between these models. Separate sets are required for aerodynamic surfaces and for the

fuselage, nacelle and landing gear. This flow of data is described in detail in Volume II. Figures 40 and 41 of that volume outline the respective requirements, and Appendix J reproduces a complete set of worksheets, as used in the demonstration case, to illustrate the method

2.2.2.5 Categorization of Structure By Type of Construction and Type of Material.

A means of categorizing types of construction and material was needed as a definitional basis for referencing historical cost data and for developing complexity factors. In the case of primary structure the categorization adopted is that used in the structural synthesis program (APAS). In the case of secondary structure, a similar categorization was not conveniently available, and it is required that a given combination of structural elements be identified and dealt with as a design concept. On a theoretical basis this looms as a difficult problem. On a practical basis it becomes manageable since only a few combinations are used. However, the area of secondary structure does not lend itself to a building block approach and must be developed by defining each individual combination. Both baseline estimating coefficients and complexity factors are made by analogy considering a comparison of characteristics.

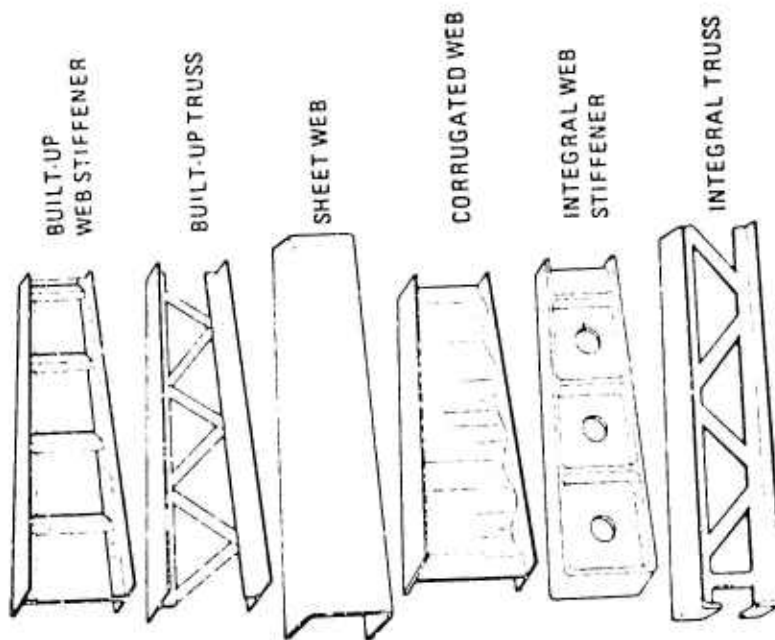
Figure 4 represents the structural definitions used for primary structure. The same definitions are used for spars as for ribs. An expanded capability can be made available for covers as shown in Figure 5 based on recent developments in the APAS program. Cost factors, however, were developed based on the earlier categorization.

Material categorizations include aluminum, titanium, low carbon steel, and stainless steel. Various composites are currently being studied under independent research and development. Extensions to the complexity factor data can be made by an analysis of the impact of a change in material on manufacturing processes as defined by the construction categories.

The study has verified that historical cost data is not available for all combinations of types of construction and material. The reason for this is simply that existing aircraft are repetitive in their use of material/construction types. Construction and material types represented by the aircraft reviewed have been determined. An example of the results is given in Table 1. A complete set of the available data is given in Volume II, Appendix G.

The estimating method selected requires a minimum of one actual data point per CER. This is needed to calibrate the structure of industrial engineering estimates involved. Additional data points are, obviously, useful and desirable. Estimating new types of construction and materials relies on a process capable of looking into the requirements of new features in terms of their impact on functional procedures; i.e., manufacturing, quality control, tooling, etc.

RIBS



COVERS

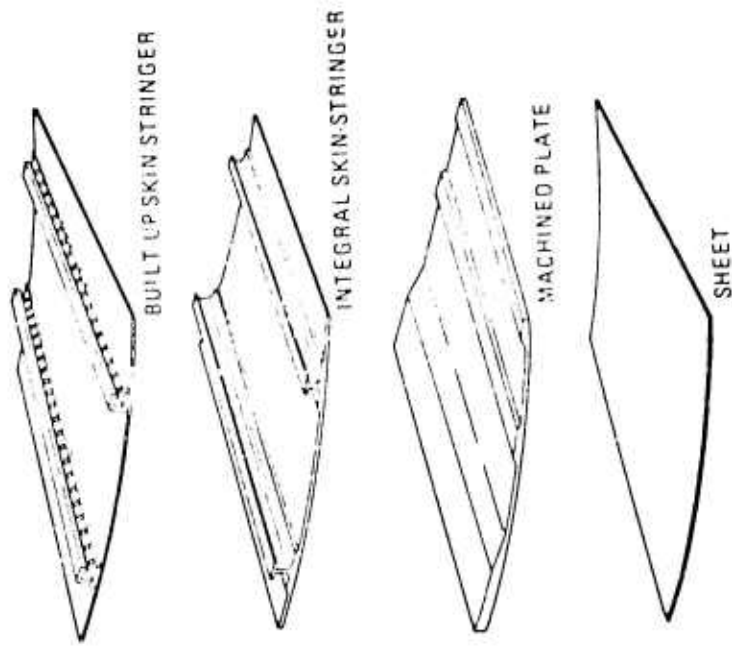


Figure 4. Definition of Ribs and Covers Types of Construction.

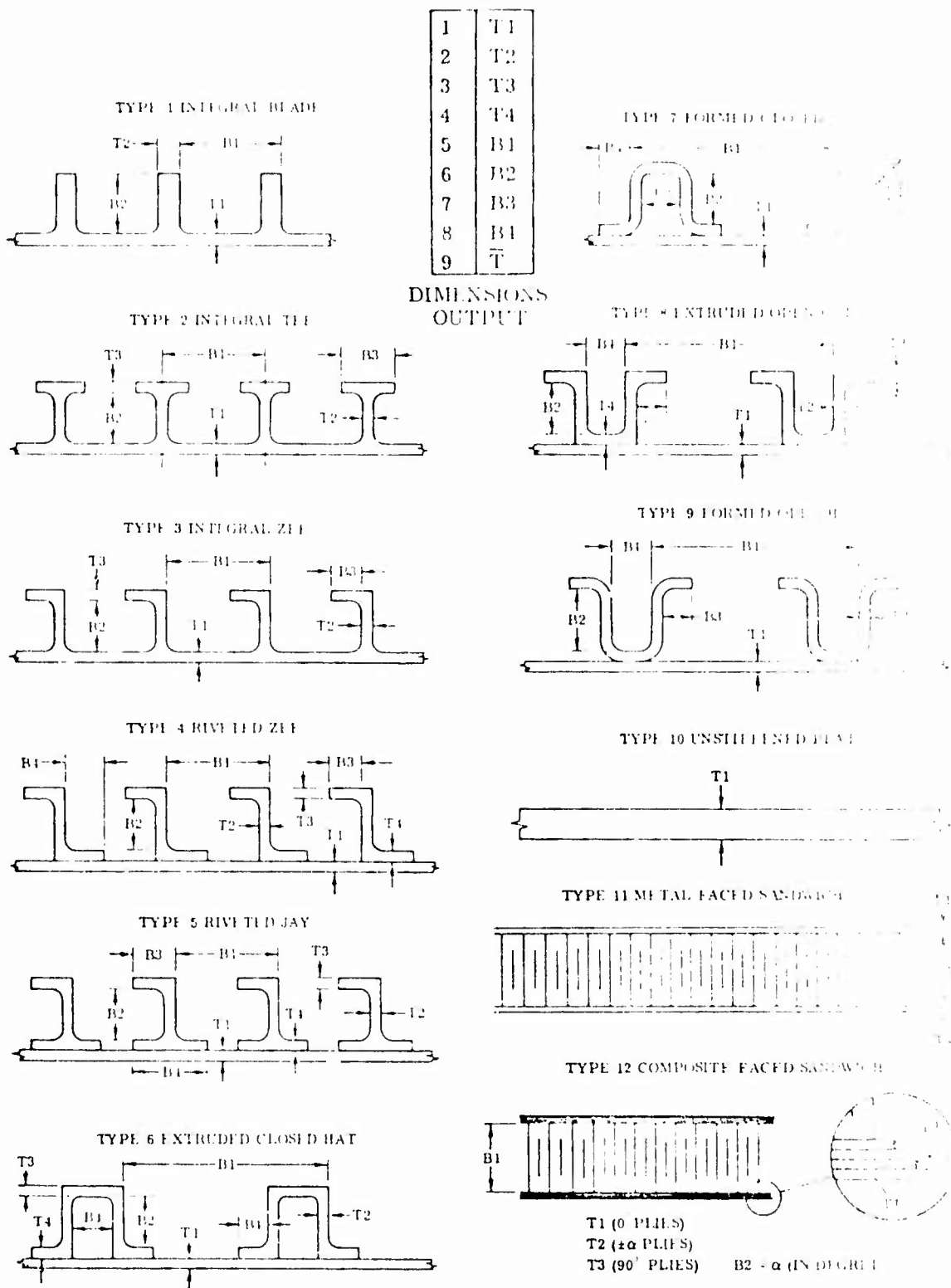


Figure 5. Structural Element Geometry - Covers.

Table 1. Construction Types Represented in the Data Sample.

Aircraft	Skins	Ribs	Spars
C-141 Horizontal Stabilizer	Built-up skin stringer	Built-up and integral truss	Built-up web stiffener
C-141 Vertical Stabilizer	Built-up skin stringer	Built-up and integral truss	Built-up and integral truss Sheet web
C-5A Horizontal Stabilizer	Integral skin stringer	Built-up truss	Built-up web stiffener
C-5A Vertical Stabilizer	Integral skin stringer	Built-up truss	Built-up web stiffener
F-111A Horizontal Stabilizer (Conventional)	Machined plate	Honeycomb core	Integral web stiffener
F-111A Horizontal Stabilizer (Boron)	Sheet	Integral web stiffener honeycomb core	Sheet web
VSX	Sheet	Built-up web stiffener	Built-up web stiffener
AX	Machined plate	Built-up web stiffener	Built-up web stiffener
VFX	Integral skin stringer	Sheet web and integral web stiffener	Sheet web
B-52 Outer Wing Panel	Machined plate	Built-up web stiffener	Built-up truss
880/990 Horizontal Stabilizer	Built-up sheet stringer	Built-up truss	Built-up web stiffener
LIT	Sheet	Sheet web	Integral web stiffener
F-111 Vertical Fin	Machined plate	Integral web stiffener and integral truss	Integral web stiffener

2.2.2.6 Investigation of Estimating Methods. An investigation of estimating methods was undertaken as part of the study in order to provide the basis for eclectically selecting the most suitable approach. This investigation was initiated as part of the feasibility study and was described in Reference 1. Stemming from this literature review and general cost research conducted by Convair, baseline candidate methods for satisfying requirements for trade and system study cost estimating techniques were postulated. Final recommendations were incorporated in the methods selected for development. Additional literature review, as described in Reference 2, has been conducted but has not altered basic conceptions.

An overview and summary of estimating methods is given in Figure 6. Traditional estimating methods have focused on questions such as the level of detail of the estimate, the administrative responsibility for the estimate, and the techniques to be used to substantiate the estimate at whatever level is used. Available techniques

	STATISTICAL (PARAMETRIC)	ANALOGY	INDUSTRIAL ENGINEERING
AIRFRAME LEVEL - PARAMETRIC	✓		
SUBSYSTEM LEVEL - PARAMETRIC	✓		
COMPONENT LEVEL ANALYSIS	○	✓	✓
GRASS ROOTS	✓	✓	✓

Figure 6. Estimating Methods.

were summarized by Rand (Reference 4) as the three techniques shown: statistical, analogy, and industrial engineering. The grass roots method specifies level, primarily in terms of organization, but does not necessarily specify technique.

Traditional methods have defined an estimating rule: The credibility of the cost estimate is directly proportional to the definition provided. Seemingly, constraints are imposed on estimating methods by input requirements, and lower levels of estimating, such as component level analysis, are not attempted in early phases of design.

The trade study estimating method is at the component level but has not attempted the further objective of being entirely statistical. This would require considerable additional data. In the meanwhile the techniques of analogy and industrial engineering analyses provide back-up approaches.

2.2.3 A DESCRIPTION OF THE METHOD. This section is intended to provide an overview of the trade study method. Figure 7 is a flow diagram for the method. (This figure is also used in Volume II), and will be used as the basis for this discussion. The basic elements of the method are highlighted in Figure 8.



Figure 8. Estimating Process Basic Elements.

Input development relates primarily to the preliminary design interface and in particular the supporting structural synthesis programs. The development of inputs will be described and illustrated. Inputs are categorized by method of handling, i.e., NAMELIST variables versus model card inputs, and by the nature of the input. These categorizations amount to almost the same thing since the method of handling is specified by the nature of the input. NAMELIST variables vary with the design characteristics whereas the model card inputs consist of estimating coefficients that are baselined to the historical data base and vary only as values are reevaluated. The estimating logic consists of a series of cost estimating relationships that will be discussed and that are listed in Appendix A. The cost output, the product of the estimating process, is the final element of the process.

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4. G. S. Levenson and S. M. Barro, Cost Estimating Relationships for Aircraft Airframes, RM-4845-PR, Rand Corp., December 1965.

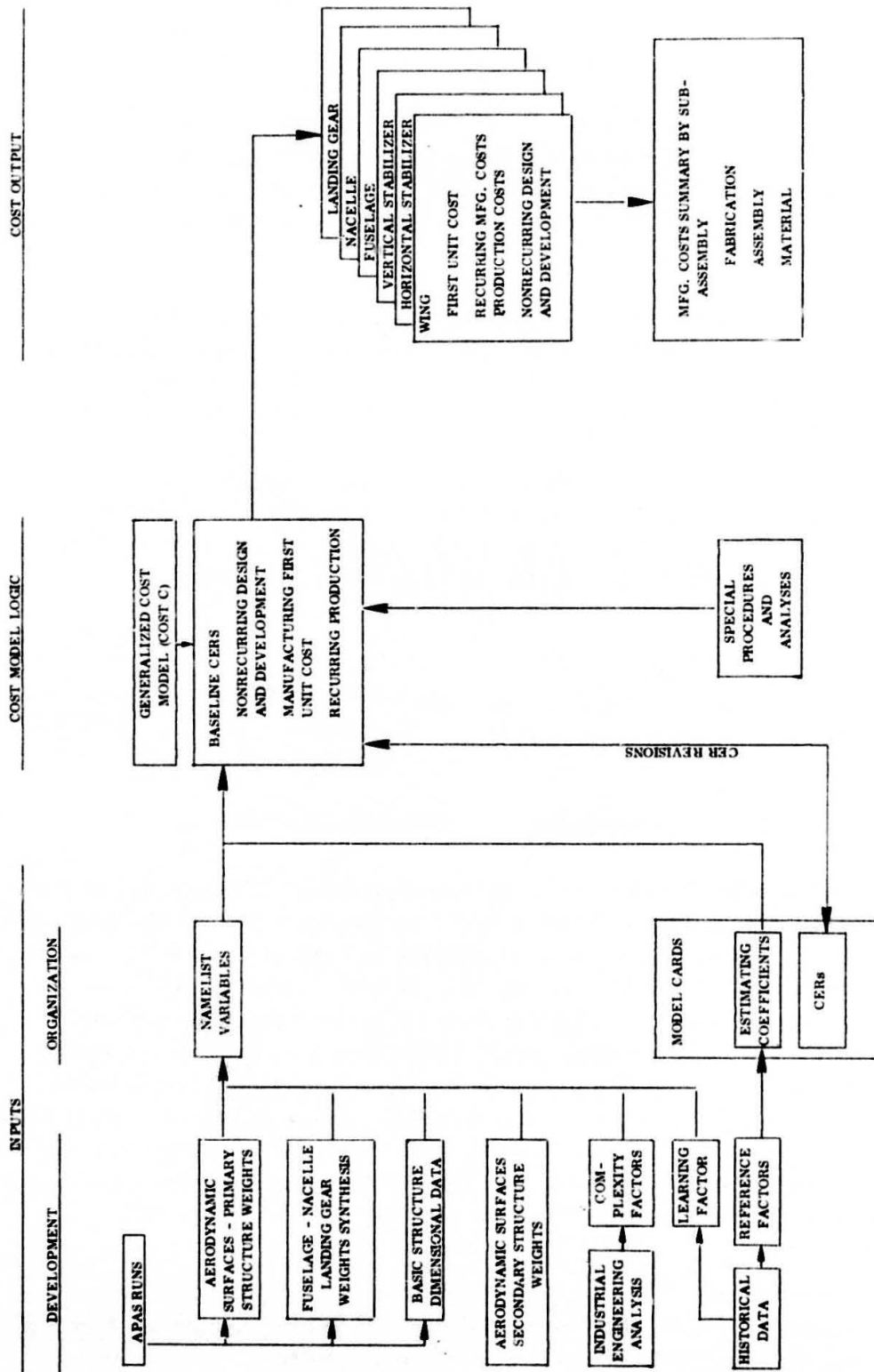


Figure 7. Trade Study Cost Estimating Method.

Cost Output

The cost output formats are a logical starting point for the method description. A complete set of output data represents 36 different computer printouts. A complete set of these is given in Volume II with their location given in Table M-1. Table 2, which also appears in Volume II, summarizes the cost printouts involved in a trade study estimate. The number of printouts varies with the number of different quantities included. Figures 9, 10, 11, and 12 show, respectively, examples of first unit cost, a production quantity (in this case RDT&E), nonrecurring design and development, and a recurring production summary. The wing is used as the example in each case. The remaining hardware elements are dealt with in a comparable manner, although the detailed list of hardware components making up each element differs. The printouts for the various production quantities, i.e., RDT&E, production quantity 1, and production quantity 2, are identical for each component.

Wing First Unit Cost, shown in Figure 9, involves definition of cost by primary and secondary structural element and by element of cost, i.e., manufacturing labor broken down into fabrication and assembly tasks and production material. Definitions for the breakdown are given in Appendix A. The use of first unit cost in the estimating process is discussed in Section 2.2.4 in connection with the derivation of CERS.

The cost of production units is estimated in the detail shown in Figure 10. This breakout is identical to the one for first unit cost, and the estimates are made simply by a learning curve projection of the first unit values.

Nonrecurring design and development costs consist of engineering labor and material; tool engineering, manufacturing, and material; manufacturing support; quality control; and manufacturing development. These are for structural subsystems only, as shown in Figure 11. Definitions are included in Appendix A.

Figure 12 provides a summary of recurring airframe production costs. This summary is provided for each of the production quantities estimates. It summarizes manufacturing items of cost and provides for the estimating of sustaining engineering and tooling for the various production quantities. Manufacturing costs are obtained from the detailed printouts. The item "assembly" comprises hardware element subassembly and major assembly, as defined for primary and secondary structure.

Generalized Cost Model (COSTC)

The basis for the cost model programming is a series of cost estimating relationships contained on model cards that are classed as input data. This is made possible by a driver program that is referred to as the COSTC program. COSTC is

Table 2. Summary of Cost Printouts for a Trade Study Estimate.

Hardware Component	Type of Cost Printout					
	First Unit Cost	RDT&E Units Cost	Production Units Quantity 1	Production Units Quantity 2	Nonrecurring Design & Development	Recurring Production Summary
Aerodynamic Surfaces:						
Wing	X	X	X	X	X	X
Horizontal Stabilizer	X	X	X	X	X	X
Vertical Stabilizer	X	X	X	X	X	X
Fuselage	X	X	X	X	X	X
Nacelles	X	X	X	X	X	X
Landing Gears	X	X	X	X	X	X

3-4 FEB CASE
CITY OF LOS ANGELES
CITY OF LOS ANGELES

1501 UNIT COST

WING

17.3A.44.

24/53/73

[illegible]

Figure 9. Wing First Unit Cost.

AEROSPACE VEHICLE STRUCTURAL COSTS
NONRECURRING DESIGN AND DEVELOPMENT COSTS

17.28.46. 01/09/75

	WING HOURS	WORT HOURS	VERT HOURS	FUSE HOURS	NACE HOURS	LOG GEAR HOURS	SUB- TOTAL HOURS	DOL LAB COSTS
BASIC STRUCT DESIGN ENGR	.152		.029	.201	.191	.079	.652	4.277
CONFIGURATION DESIGN ENGR							.75	4.919
ENGINEERING MATERIAL								.492
TOTAL TRADE STUDY ENGR							1.402	9.688

BASIC TOOL MFG HOURS	8.533		.724	4.329	4.070	.049	17.854	
PATE TOOLING MFG HOURS							4.397	
TOTAL TOOL MFG							22.251	139.229
BASIC TOOL ENGRG HOURS							7.142	
PATE TOOL ENGRG HOURS							.652	
TOTAL TOOL ENGRG							7.794	46.330
LOG ENGR & PLANT ENGR							.445	2.469
TOOLING MTL & OTHER DOLLARS								22.241
MANUFACTURING SUPPORT DOLLARS								.492
QUALITY CONTROL								
TOTALS							1.342	9.179
							33.229	228.139

Figure 11. Nonrecurring Design and Development Costs.

AEROSPACE VEHICLE STRUCTURAL COSTS
RECURRING AIRFRAME PRODUCTION COSTS (SUMMARY)

17.29.66. 01/03/75

ROUTE	WING		WORT		VERT		FUSE		WIDE		DO		SUB-		PROD	
	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	UNITS	UNITS
SUSTAINING COSTS																
SUSTAINING TOOLING																
MANUFACTURING																
TOTALS																
SUSTAINING COSTS																
SUSTAINING TOOLING																
MANUFACTURING																
TOTALS																
SUSTAINING COSTS																
SUSTAINING TOOLING																
MANUFACTURING																
TOTALS																

Figure 12. Recurring Airframe Production Costs (Summary).

a generalized cost model that acts as a data manager of inputs consisting of the model cards containing instructions for calculations and variables used in these calculations. The variables are handled by the NAMELIST convention. The CERs are entered on the model cards as standard Fortran statements (F-cards) or as a coded entry (Z-cards).

The programming approach using COSTC is an integral part of the cost model computer program, and its operation is discussed further in Section IV. For the purpose of describing the estimating method, however, some idea of the model card CER entry is needed. Figure 13 is a sample of model card entries showing five types (coding appears as the first letter of each line - except in the case of a so-called blank card).

- a. The C-card, which functions as a standard comment card.
- b. The D-card causes the printing of the line just computed by the preceding calculation card (Z-, R-, or F-) and columns 3-38 are printed as the title for that line.
- c. The F-card, a generalization of the Z card in which the computational formula is written on the card in a Fortran - compatible format, rather than specifying a code for the desired formula as in the case of the Z-card.
- d. The R-card is again a special case of the Z-card. It is used to transfer data within the SAV matrix and is explained in Volume II, Appendix A.
- e. The blank-card is identified by the lack of symbols in the first two columns. This card is ignored in the output printout but will be printed in the model card input printout. It occurs just under F 38 1 in Figure 13 causing the printing of the symbols WC1 and E7, identifying the values appearing directly above in the line above. (Key punch must coordinate the spacing.)

A complete listing of the model cards used is contained in Volume II, Appendix A. This list defines the total set of calculations used in the estimating process. Z-cards have been mentioned but not exemplified. They are explained in Volume II, Appendix A.

As an example of the meaning ascribed to the model card entries, in Figure 13, the sixth F-card entry appears as follows:

```
F 38 1 CB1 WNG * 55.0 * WD1 WNG** .67
```

This card says, first that it is an F-card, that the results of the calculation called for are to be recorded in the SAV matrix on line 38, column 1, and that the

```

C F 34 3 (10,1)+(10,2)+(16,3)+(16,4)+(16,5)+(16,6)
F 34 0 (10,7) * 1.0
D ASSEMBLY
R 35 1 0 3 4 31 1
D STRUCTURAL BOX SUB-TOTALS
F 36 1 (35,1) * RM WNG
F 36 2 (35,2) * RM WNG
F 36 3 (35,3) * RM WNG
D LABOR COSTS ($)
C
C SECONDARY STRUCTURE
F 38 1 CC1 WNG * 55.0 * WD1 WNG**67
      "C1
      E7
F 38 2 CC1 WNG * 48.0 * WD1 WNG**67
      "F1
      F1
F 38 6 WL1 WNG**77 * RMC10 WNG * SF10 WNG
D LEADING EDGE
F 39 1 CC2 WNG * 29.0 * WD2 WNG**67
      "C2
      E8
F 39 2 CC2 WNG * 23.0 * WD2 WNG**67
      "F2
      F2
F 39 6 WL2 WNG**77 * RMC11 WNG * SF11 WNG
D TRAILING EDGE
F 40 1 CC3 WNG * 35. * WD3 WNG**67
F 40 2 CC3 WNG * 47. * WD3 WNG**67
F 40 6 WL3 WNG**77 * RMC12 WNG * SF12 WNG
D ALLERONS
F 41 1 CC4 WNG * 36. * WD4 WNG**67
F 41 2 CC4 WNG * 34. * WD4 WNG**67
F 41 6 WL4 WNG**77 * RMC13 WNG * SF13 WNG
D FAIRINGS

```

Figure 13. Sample Model Card Entries.

calculation to be performed is:

$$\text{Cost} = (\text{CB1 WNG})(55)(\text{WD1 WNG})^{.67}$$

where

CB1 WNG	A complexity factor
55 WCI	A reference cost per pound
WD1 WNG	Weight of the wing leading edge
.67 E7	Weight-cost scaling exponent

The SAV matrix is a feature of the COSTC programming. It consists of a matrix in which the lines and columns identify the address where intermediate calculations are stored. The address designations may themselves be used as inputs to the calculation process. A SAV matrix printout for the demonstration case is given in Appendix C, Volume II.

The COSTC program can, and perhaps should, be treated as a transparent program (i.e., looking only at inputs and outputs). This can be done without any fundamental loss in program understanding. Use of the program does, however, involve understanding several conventions such as that exemplified above. The functions of the various types of model cards used are described in Appendix A of Volume II, including the rules applicable to the use of each.

Cost Estimating Relationships

A series of cost estimating relationships have been derived for estimating the sets of costs shown in Table 2 to the level of detail exemplified in Figures 9 through 12. The number and type of CERs are summarized in Figure 14. These CERs are listed in Appendix A. Their derivation is discussed in the following section. Volume II gives a complete synopsis of the CERs relating cost estimates to equational form to input requirements and sources and to the location of back-up data for cost estimating coefficients.

Since the cost estimating relationships are entered on model cards, they may be revised simply by a change to the relevant model card and a change, where necessary, to the NAMELIST variables and the COMMON block. The latter change is necessary whenever the new CER adds additional NAMELIST variables. Changes involving variables used only for the affected calculation produce no constraint. The NAMELIST retains the conventional convenience of changing all uses of the variable with a single input change. CERs can thus, themselves, be classed and handled as input data.

●	FIRST UNIT COST:	DETAIL FABRICATION	(2)
		SUBASSEMBLY	(2)
		BASIC STRUCTURE ASSEMBLY	(11)
		STRUCTURAL MATERIAL	(4)
		PRIMARY ASSEMBLY AND MAJOR MATE	(2)
●	RECURRING PRODUCTION COST		(1)
●	NONRECURRING DESIGN AND DEVELOPMENT		
		ENGINEERING	(5)
		TOOLING	(9)
		MANUFACTURING SUPPORT	(1)
		QUALITY CONTROL	(2)
●	RECURRING PRODUCTION COSTS (SUMMARY)		(6)
			<hr/>
			45

Figure 14. Number and Type of CERs.

The cost model logic is based on CERs of a certain form, but the definition also includes a specific set of baseline estimating coefficients. These are based on an evaluation of the historical cost data base available at a given point in time. These coefficients are called out on the model cards, and the mechanical process for changing them represents simply a revision to a particular input card. The basis for the change, however, typically involves a reevaluation of the data base.

Each of the CER forms, its derivation, and the make up of the estimating coefficients is discussed below in the section on CER derivations. However, in order to explain the basic idea of the estimating method, a sample of one CER used in each of three cost categories is presented in Figure 15. Numerous other examples might have been cited. This will also serve as the basis for the explanation of inputs and input organization in connection with Figure 7, which follows later. Figure 16, produced from Figure 9, identifies which costs are estimated by means of the above CERs.

The above discussion leads logically into a discussion of inputs and input organization. It is necessary, however, to digress to cover the item of special procedures and analyses shown in Figure 7.

Special Procedures and Analyses

These are supplements to the basic estimating logic. They are not specifically defined but are developed as the need arises for estimating problems that are not answered by the programmed CERs. A library of these would be maintained for (1) possible use as a basis for modifying the estimating logic, and (2) analogs to be used in making future estimates. Examples of the special cases that can occur are:

- a. Special bonding processes such as adhesive and weld bonding.
- b. Combinations of type of construction, as for example, a rib design that calls for a combination of machined caps and built-up center web.
- c. Structure involving fuel tanks that are integral to the structure.
- d. Special structural features peculiar to the particular design.

Some examples of supplemental estimating were given in Reference 1, namely honeycomb structure and fabric composites used as bonded reinforcement to conventional structure. These procedures and analyses do not, by their nature, lend themselves to standard definition and require solutions outside the model.

Inputs and Input Organization

Figure 7 shows inputs organized into two categories: NAMELIST variables and

Rib Detail Fabrication Hours

$$H_1 = \frac{W_1 CF_1 + W_1 CF_1 + W_1 CF_1 + HF_1 + WT_1}{WT_1} E_1$$

where: W_1 Weight of ribs of three alternative construction and material types represented by corresponding complexities.

CF_1 Complexity factor corresponding to rib type

WT_1 Sum of the rib weights

HF_1 Fabrication hours per pound for structural component for baseline configuration.

E_1 Weight-sealing exponent.

Rib Subassembly Hours

$$H_1 = \frac{W_1 CM_1 + W_1 CM_1 + W_1 CM_1 + HF_1 + WT_1}{WT_1} E_1$$

where: CM_1 Complexity factor for given material and construction technique.

HF_1 Subassembly hours per pound for baseline configuration.

E_1 Weight-sealing exponent.

Rib Structural Material Cost

$$M_1 = W_1^G (RMC_1) (SF_1)$$

where: RMC_1 Raw material cost per pound.

SF_1 Scrappage factor

G Weight sealing exponent

Figure 15. CER Examples for Manufacturing First Unit Cost.

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	DETAIL FAB HOURS	SUB- ASSY HOURS	MAJOR ASSY HOURS	PRIM- ASSY HOURS	MAJOR WAVE HOURS	MAIL COST \$	TOTAL LABOR \$	TOTAL HOURS	TOTAL LABOR \$
STRUCTURAL BOX									
WINGS	4039	1061				12629			
SPARS	12758	7696				51551			
COVERS									
ASSEMBLY			40033			64066			
STRUCTURAL BOX SUB-TOTALS	25245	15144	40039			161560			
LABOR COSTS (\$)	154739	95756	252845						
STRUCTURAL STRUCTURE									
WINGS	4382	4067				5443			
SPARS	2491	2160				2154			
COVERS	42612	24771				14456			
WINGS	9229	7222				9734			
SPARS	6319	5114				4418			
COVERS									
STRUCTURE									
WINGS	1131	494				3384			
SPARS	1621	3775				10114			
COVERS									
STRUCTURE									
WINGS									
SPARS									
COVERS									
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COVERS									
STRUCTURE									
WINGS									
SPARS									
COVERS									

Figure 16. Wing First Unit Cost.

model card coefficients, neglecting CERs as inputs. Figure 17 will serve to illustrate the basic categorization, and other CER forms to be described will be seen to follow this same general pattern. The meanings of the symbols illustrated are as follows:

- H_i = Fabrication hours for ribs, frames, spars, longerons and covers corresponding to element inputs for element estimated.
- W_i = A series of weights for the component estimated coded as: W_1 , W_2 , and W_3 for three possible combinations of rib types; W_4 , W_5 , and W_6 for spars, etc.
- CF_i = A series of complexity factors corresponding to the above series.
- WT_i = Computer summation of weights:
 WT = Sum of rib weights
 $WT1$ = Sum of spar weights
 $WT2$ = Sum of cover weights
- HF_i = A series of reference cost per pound values for ribs, frames, spars, longerons, and covers related to fabrication labor.
- E_i = A series of weight scaling exponents for ribs, frames, spars, longerons, and covers related to fabrication labor.
- R = Assumed labor rate.

The size parameters, which are generally, but not always, weight, and the complexity factors vary with the design characteristics of the component estimated and are handled as NAMELIST (\$SIZE) variables. Figure 18 illustrates the associated computer program input card and shows these variables for the wing. The other variables shown relate to the remaining CERs. A NAMELIST variables dictionary is contained in Volume II, Appendix D. As shown, learning curve variables are handled in a separate NAMELIST, that is \$CURVE. The NAMELIST \$SUMMARY applies to the system costing method.

The model card coefficients consist of the terms HF_i and E_i . These are baseline estimating terms and are based on an analysis of historical data. This analysis and the nature of the data base changes that might give rise to a change in their value is explained as part of the CER derivation. As mentioned before, all such changes, are handled as model card revisions necessitating key punching revised cards or the use of Interactive Graphics, which would involve a tape file change by graphic display and keyboard control.

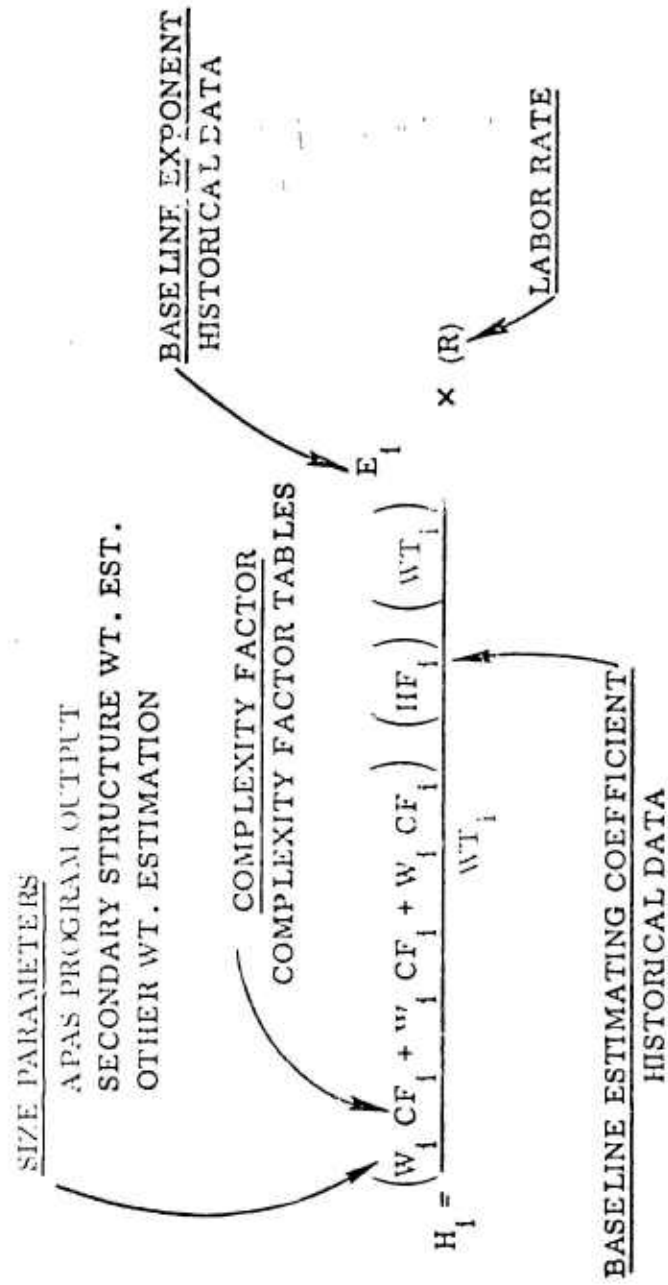


Figure 17. CER Form for Costing Concept.

[illegible]

Labor rates are handled as a NAMELIST input, RM = 6.29 in the illustration. The example in Figure 17 is conceptual only, however, since labor rates are applied at an aggregate level.

The NAMELIST dictionary defines all such inputs. Model card inputs are called out on the model cards. Volume II provides a complete discussion of inputs as they derive from the individual CERs, starting on page 42. Figure 19 provides a summary view of input organization.

Input Development

Volume II describes a complete set of worksheets that would be used for working up inputs for a given estimate. These inputs are discussed in the description of the CERs themselves. The process of input development is depicted in general terms in Figure 7. This picture is amplified by Figure 20, which will be used for a discussion of input development. Input development is crucial since the availability of the proper inputs determines the success of the predesign estimating process. Also the development is not completely objective and needs to provide for the experience and judgment of the cost analyst. This figure also focuses in further on the interface with the design synthesis programs.

The source of APAS inputs is not specified, but would be determined within a given predesign activity. The input requirement is defined in Worksheet 1, page 430, Volume II, Appendix J. A separate APAS run is required for each of the structural elements: wing, horizontal stabilizer, etc. The various items of dimensional data used as CER inputs are, for the most part, throughputs to the APAS program.

The aerodynamic surfaces secondary structure synthesis and weight analysis program has a set of inputs as defined in Worksheet 3, page 440, Volume II, Appendix J. This program is also referred to as the leading-edge, trailing-edge program.

Labor rates are applied to reflect the time period involved and the cost performance of the contractor. Learning curve factors are based on historical data. This study, however, has not been addressed to this problem at the detailed level at which production costs have been projected. Costing factors include baseline cost estimating coefficients, complexity factors, and direct estimating factors. Their development is a subject of discussion under CER derivation.

2.2.4 DERIVATION OF COST ESTIMATING RELATIONSHIPS. The CERs used in the trade study cost estimating method have been categorized as follows:

- a. First Unit Manufacturing Costs.
- b. Recurring Unit Costs.

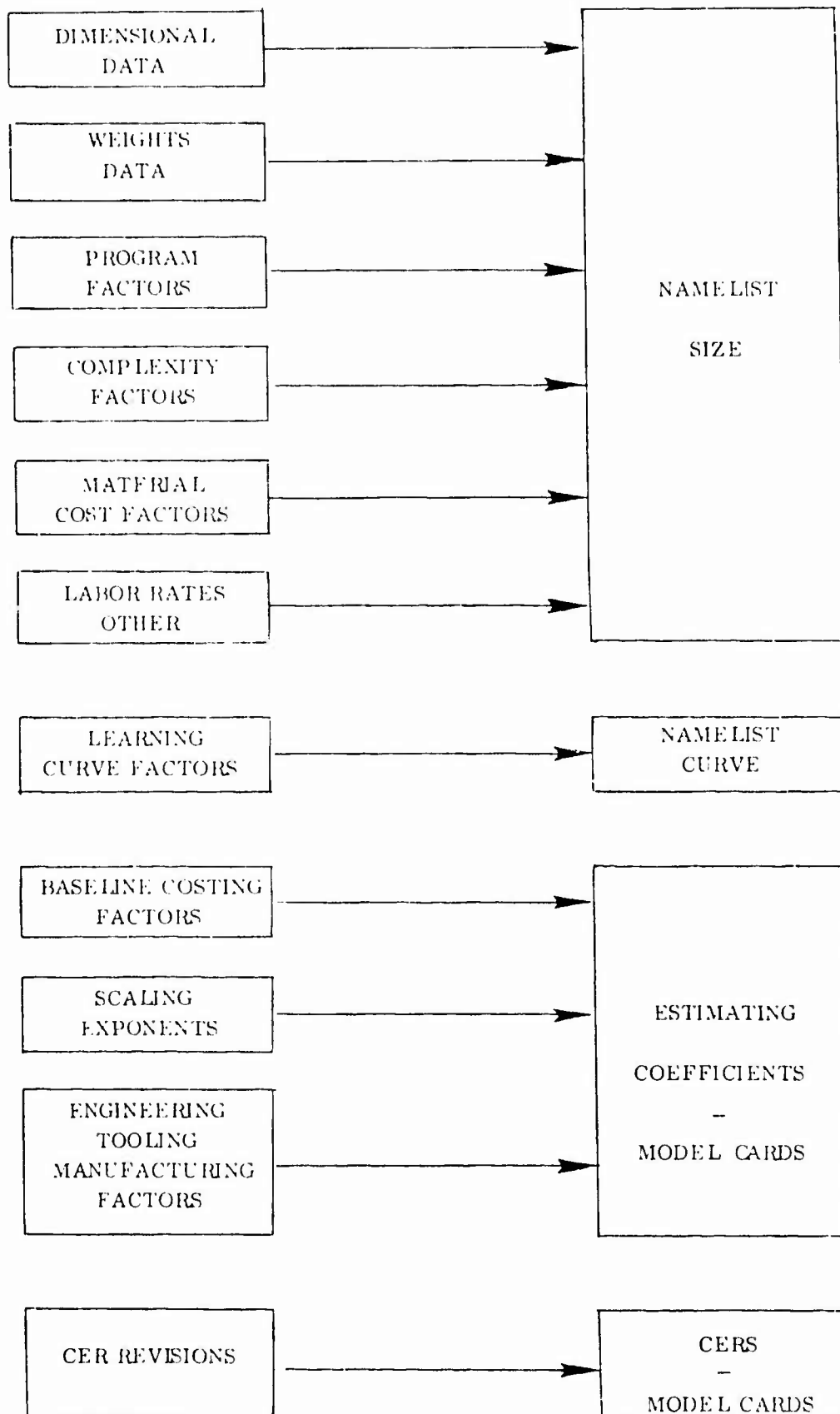


Figure 19. Cost Model Input Summary.

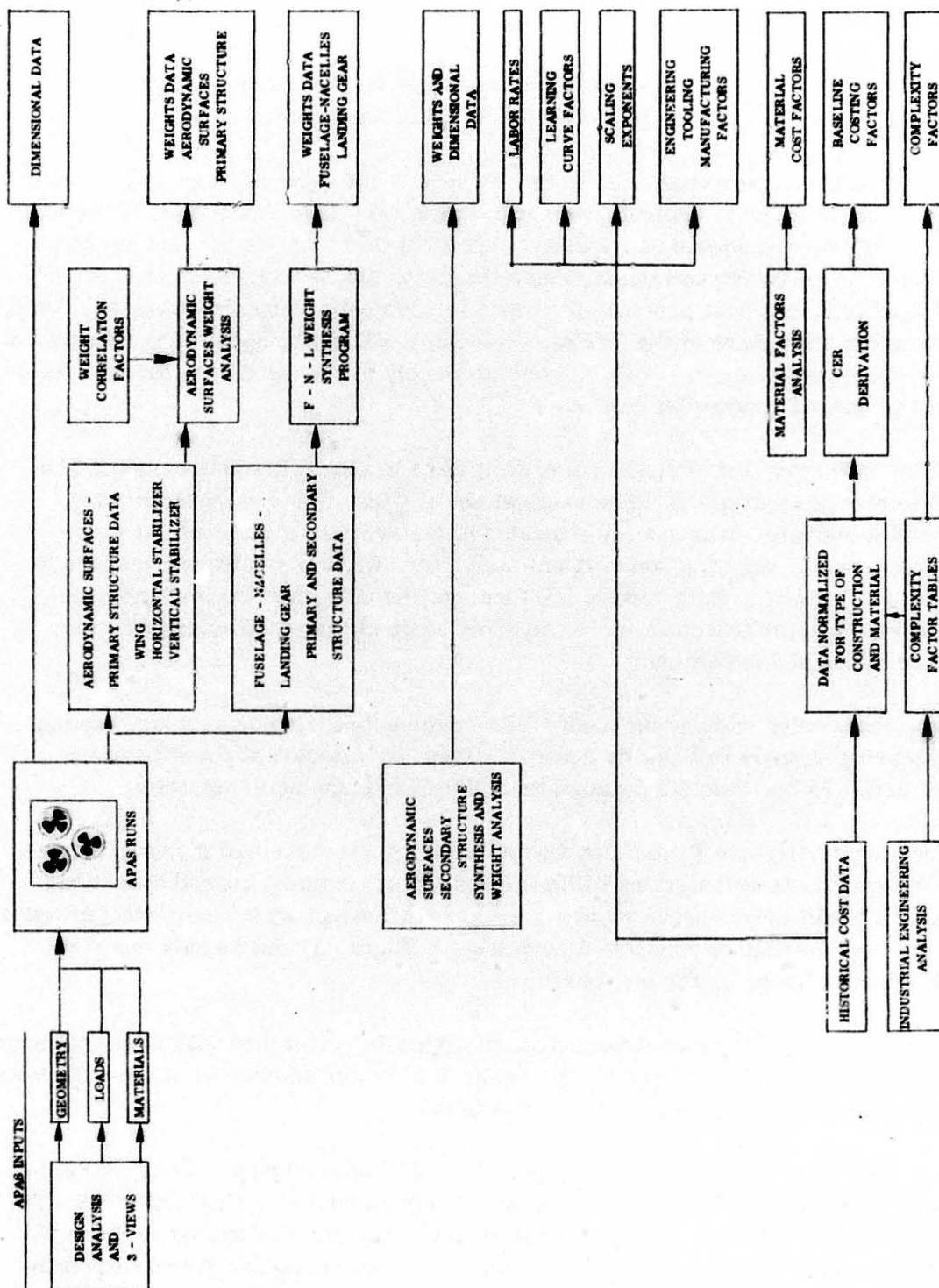


Figure 20. Input Development.

- c. Nonrecurring Design and Development.
- d. Recurring Airframe Production Costs (Summary)

Figures 9, 10, 11, and 12 serve to illustrate, respectively, these categories. CER derivation will be discussed with reference to this framework.

First unit costs and recurring unit costs, as seen from Figures 9 and 10, use the same breakdown of cost, subject, however, to the variations introduced because of different hardware elements considered. The first unit cost set of numbers is not additive to the recurring unit costs, since the latter starts with the first unit. The estimate of first unit cost provides the basis for projecting production costs. This is reflected in the nature of the CERs. Category a CERs use hardware characteristics to estimate costs. Category b CERs consist merely of the equational forms used to project the cost of production quantities.

As can be seen from Table 2, the other dimension to the CER requirement is the hardware element estimated. The original set of CERs was developed for the horizontal stabilizer. These were extended to the remaining elements of aerodynamic surfaces, the wing and vertical stabilizer, with no significant changes to the basic CER forms. Extension to the fuselage, nacelle, and landing gear, accomplished since the interim report, involved some changes. The reasons for these are discussed in Section 3.

Nonrecurring design and development CERs cover primarily engineering, tooling, manufacturing support and quality control. They are effected at the subsystem level of detail rather than the detailed level used for manufacturing costs.

The Recurring Airframe Production Costs Summary provides CERs to summarize manufacturing costs and a set of CERs for Sustaining Engineering and Sustaining Tooling. Estimates are provided for three alternative unit quantities: RDT&E quantities and two alternative production quantities. (Figure 12 shows only one production quantity based on the test case.)

The complete set of CERs is summarized in Appendix A together with cost definitions. The complete set is also discussed in Volume II from the standpoint of the CER form, its related inputs, and the sources of these inputs.

2.2.4.1 First Unit Manufacturing Costs. Figure 21 is marked to identify in terms of output, the basic CER forms used to estimate manufacturing first unit cost. The vertical stabilizer is used in the example so that a comparison to Figure 9 can be made to give an idea of the difference in secondary structure components between hardware elements.

The CERs used to estimate detail fabrication and subassembly labor hours are based on a costing concept that predominates the manufacturing first unit CERs. This concept is illustrated in Figure 22. It is applied to both primary and secondary structure.

The concept relies on a CER that relates the results of a definition of a given hardware element in terms of its size and relative complexity of manufacture. The analysis leading to the definition of size is performed by various design and weight synthesis programs. Size is usually, but not always, defined in terms of weight. Complexity is defined in terms of type of material and type of construction and is symbolized by a numerical complexity factor. In the case of primary structure, the CER develops a complexity weighting according to the mix of types of construction and/or material and uses this as a multiplier of a baseline cost per pound coefficient then scales this product against the weight of the component using a baseline scaling exponent. Historical cost data is used in developing the baseline cost per pound and in establishing that the scaling exponent can be considered a constant. The CER form allows for consideration of three different material or construction types. In the case of secondary structure, the concept remains the same but the mix of types of construction and material does not frequently occur at the level of breakdown of the secondary structure components, and the weighting of complexity factors is not provided for.

One translation of this concept to a CER form has been illustrated in Figure 17, which gives a specific CER form cited to illustrate the basis for the categorization of inputs. This form is used to estimate detail fabrication and subassembly labor for ribs, frames, spars, longerons, and covers.

The salient features of the concept are:

- a. The determination of means of estimating suitable size parameters.
- b. The development of standard definitions of type of material and construction.
- c. A means for developing quantified complexity factors.
- d. The use of historical cost data to develop baseline estimating coefficients.
- e. The formulation of estimating relationships using the above factors.

The estimation of size parameters in an iterative fashion, with consideration of sizing effects, is accomplished by means of the supporting structural synthesis programs, coupled with preliminary design and vehicle sizing activities. The required parameters (i.e., model inputs) can be developed manually for a point estimate, however, the requisite level of detail is not usually an objective in pre-

FIRST UNIT COST

VERTICAL

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	DETAIL FAB HOURS	SUB- ASSY HOURS	MAJOR ASSY HOURS	PRIM- ASSY HOURS	MAJOR RATE HOURS	MATL COST \$	TOTAL LABOR HOURS	TOTAL LABOR \$	TOTAL
STRUCTURAL BOX									
RINS	634	172			(5)	616			
SPARS	1372	243				3629			
COVERS	2439	1636				4357			
ASSEMBLY			3251	(3)		5544			
SUB-TOTALS	4425	2350	3251			14146			
LABOR COSTS (\$)	27311	12356	20512						
SECONDARY STRUCTURE									
LEADING EDGE	2236	2220			(8)	2195			
TRAILING EDGE	543	513				612			
FACING	740	593				364			
TIPS	1272	952				1513			
ATTACHMENT STRUCTURE	373	536				2310			
ACCESS & OTHER COORS	404	373				593			
WINGS, BRACKETS, SEALS	1053	5563				4135			
ASSEMBLY			3938	(4)		4504			
SUB-TOTAL	8552	10703	3938			16015			
LABOR COSTS (\$)	54420	67123	24773						
VERTICAL SUB-TOTAL	13076	12753	7200	(10)					
VERTICAL WORK	1328	1275	720		(11)	30161			
VERTICAL TOTAL	14394	14028	7919			3316			
LABOR COSTS (\$)	50476	48237	49913			33177			
TOTALS							40692	255950	269124

Figure 21. Vertical Stabilizer First Unit Cost.

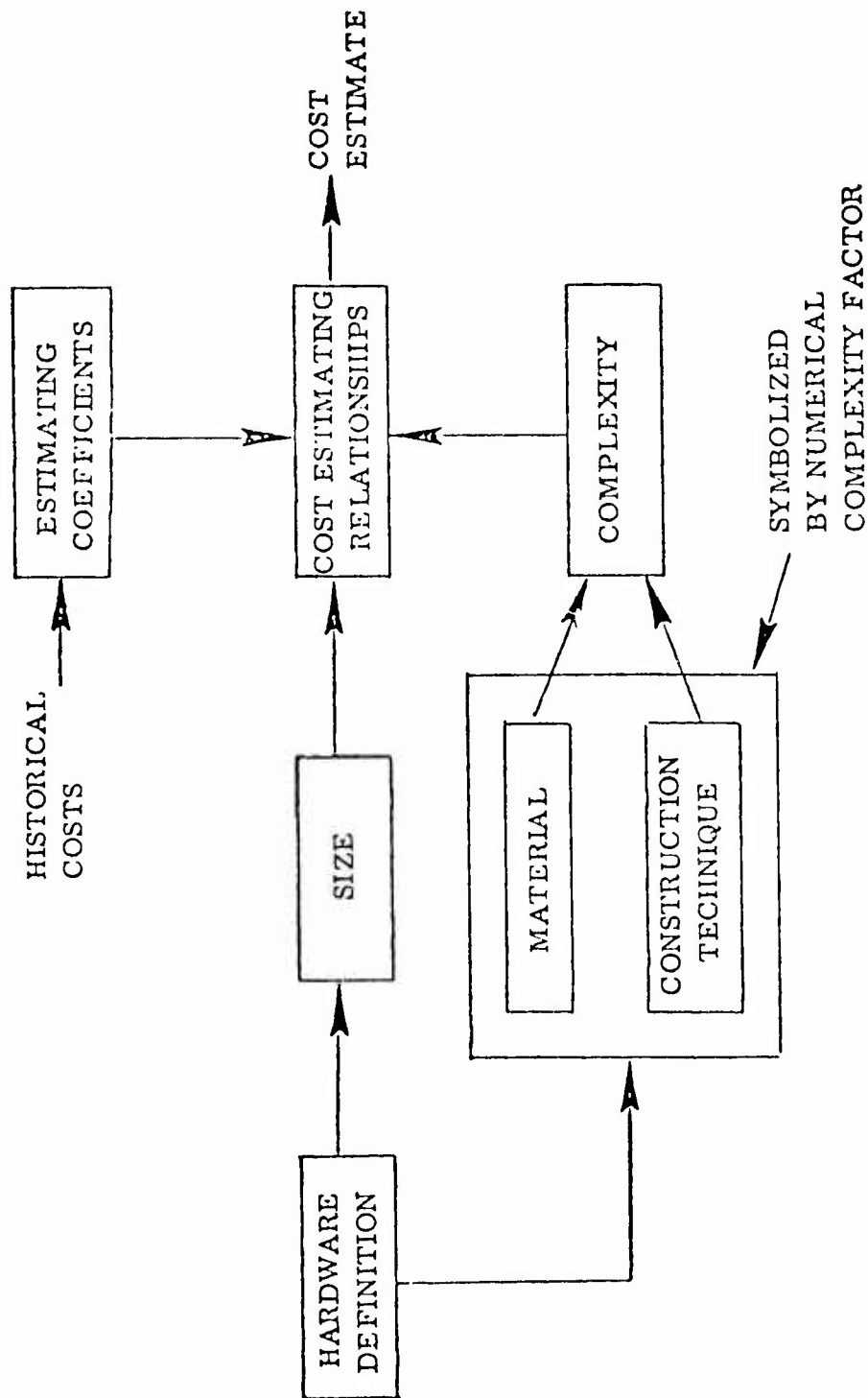


Figure 22. Costing Concept.

design without the synthesis programs. The supporting synthesis programs are discussed in Section V.

Definitions of material and construction types, in the case of primary structure, are based on those used for structural synthesis and weight estimation. An alternative would have been the definition and level of detail used for cost accounting. In the case of secondary structure, definitions are based on standard weight statement definitions.

The development of complexity factors for estimating manufacturing first unit cost is discussed in Volume II, Section 2.3.5. As explained, complexity factors were developed and summarized in a series of tables to support the estimating of the defined types of material and construction. These tables are included in the Estimating Handbook, Section 2.3. The data from the series of industrial engineering studies that served as the basis for development of these factors appears in Appendix G, Volume II. The industrial engineering estimates were based on an assumed first lot size of 32 units. Average learning curve values were determined based on manufacturing experience to arrive at factors for determining the first unit cost.

Figure 23 gives a sample of manufacturing operations for a built-up web stiffener with four types of materials showing the total estimated hours used as ratios for evaluating the impact of different types of material. The complete set of operations is given in Appendix G for the various types of construction covered. Table 3 shows, as an example, a summarization in the form of a completed complexity factor table.

Volume II (Section 2.3.6) also describes the derivation of baseline estimating coefficients. The final contract presentation, however, indicates the need for additional clarification. The steps in the procedure are outlined in Figure 24. The starting point is the historical cost data collected for each type of cost for a given component of a hardware element. An example is given in Figure 25, which shows hours per pound against weight as the size parameter for rib detailed fabrication. Normalized data is produced by adjusting each data point by its corresponding complexity. This involves identifying the type of construction and material represented and dividing the data point by the corresponding complexity value. The effect of this process is to normalize all data points to the type of construction and material to which the complexity is referenced. In this example, it is seen from Table 3 that this is built-up web stiffener with aluminum as the material, represented by a complexity factor of 1.0. Applying this process to each of the data points results in the adjustments shown in Figure 26.

The next step in the development of the estimating coefficient is the fitting of a curve to the data. This step is also illustrated in Figure 26. A basic assumption is made at this point: that the scaling of hours per pound with weight is a constant of

RIB: BUILT-UP WEB STIFFENER (SAMPLE SIZE: 48 × 12 × 2 IN.)

	MATERIAL			
	LOW-CARBON STEEL	TITANIUM	STAINLESS STEEL	ALUMINUM
MANUFACTURING OPERATION:				
FABRICATION OF RAILS:				
SET-UP SAW	0.50	0.50	0.50	0.50
SAW	0.4	0.75	1.11	0.30
BURR EDGES	0.42	0.75	1.11	0.30
SET-UP ROUTER	0.50	0.50	0.50	0.50
ROUTE STRINGER CUTOUTS	0.98	1.75	2.50	0.70
BURR	0.42	0.75	1.11	0.30
TOTAL DETAIL FABRICATION				
	17.24	21.40	25.48	16.30

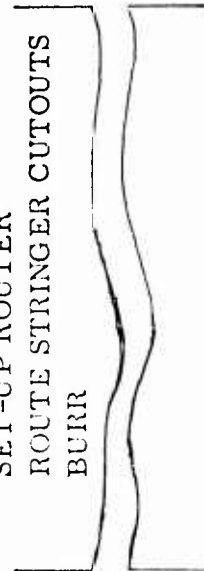


Figure 23. Detailed Industrial Engineering Analysis.

Table 3. Aerodynamics Surfaces Rib Complexity Factors -
Detail Fabrication.

STRUCTURAL ELEMENT - CER INPUT SYMBOL	MATERIAL TYPE	CONSTRUCTION TYPE					
		BUILT - UP WEB STIF- FENER	BUILT - UP TRUSS	SHEET WEB	CORRU- GATED WEB	INTEG- RAL WEB STIF- FENER	INTEG- RAL TRUSS
RIBS - DETAIL FABRI- CATION (CF)	ALUMINUM	1.0	0.70	0.52	0.51	0.99	0.96
	TITANIUM	1.31	0.95	0.59	0.57	1.82	1.86
	LOW CARBON STEEL	1.05	0.77	0.54	0.53	1.21	1.24
	STAINLESS STEEL	1.56	1.15	0.64	0.62	2.48	2.54

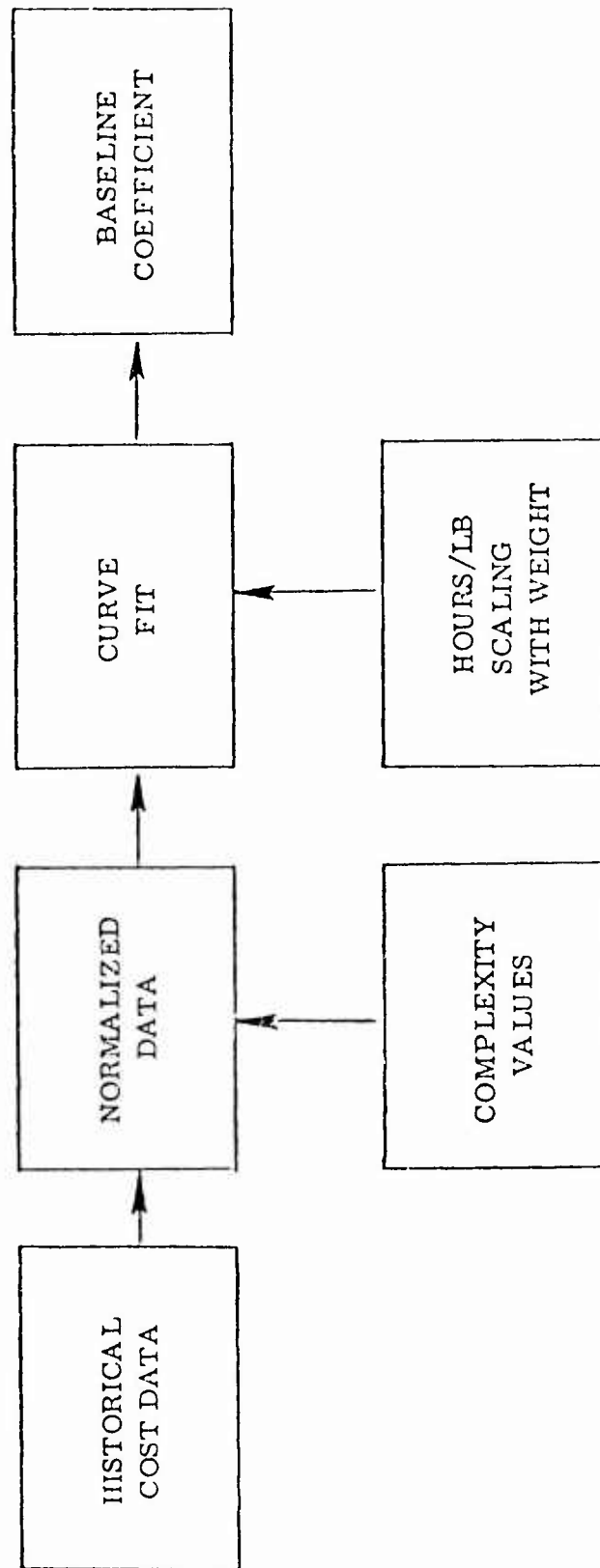


Figure 24. Derivation of Estimating Coefficients.

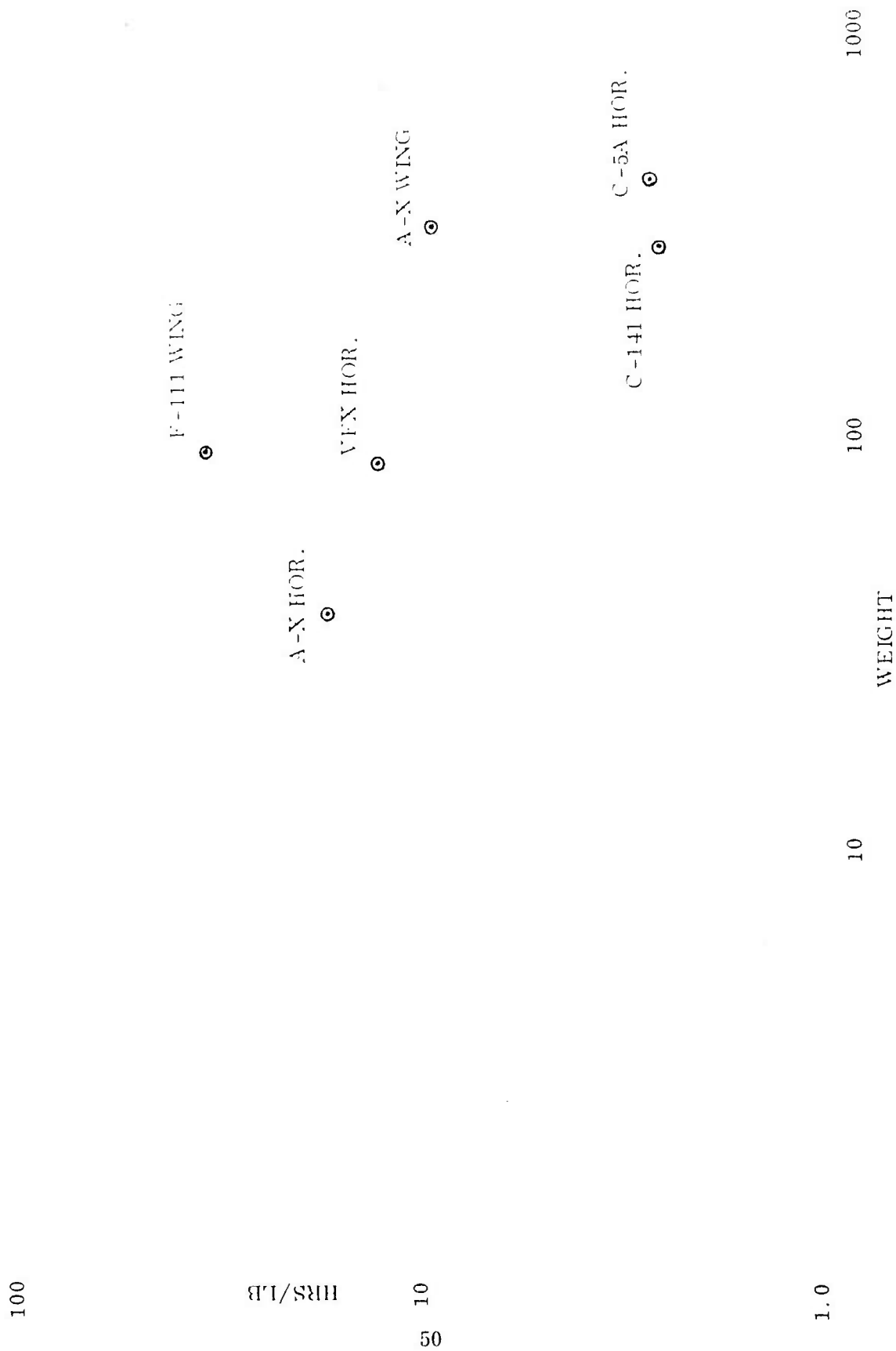


Figure 25. Historical Cost Data - Rib Detail Fabrication.

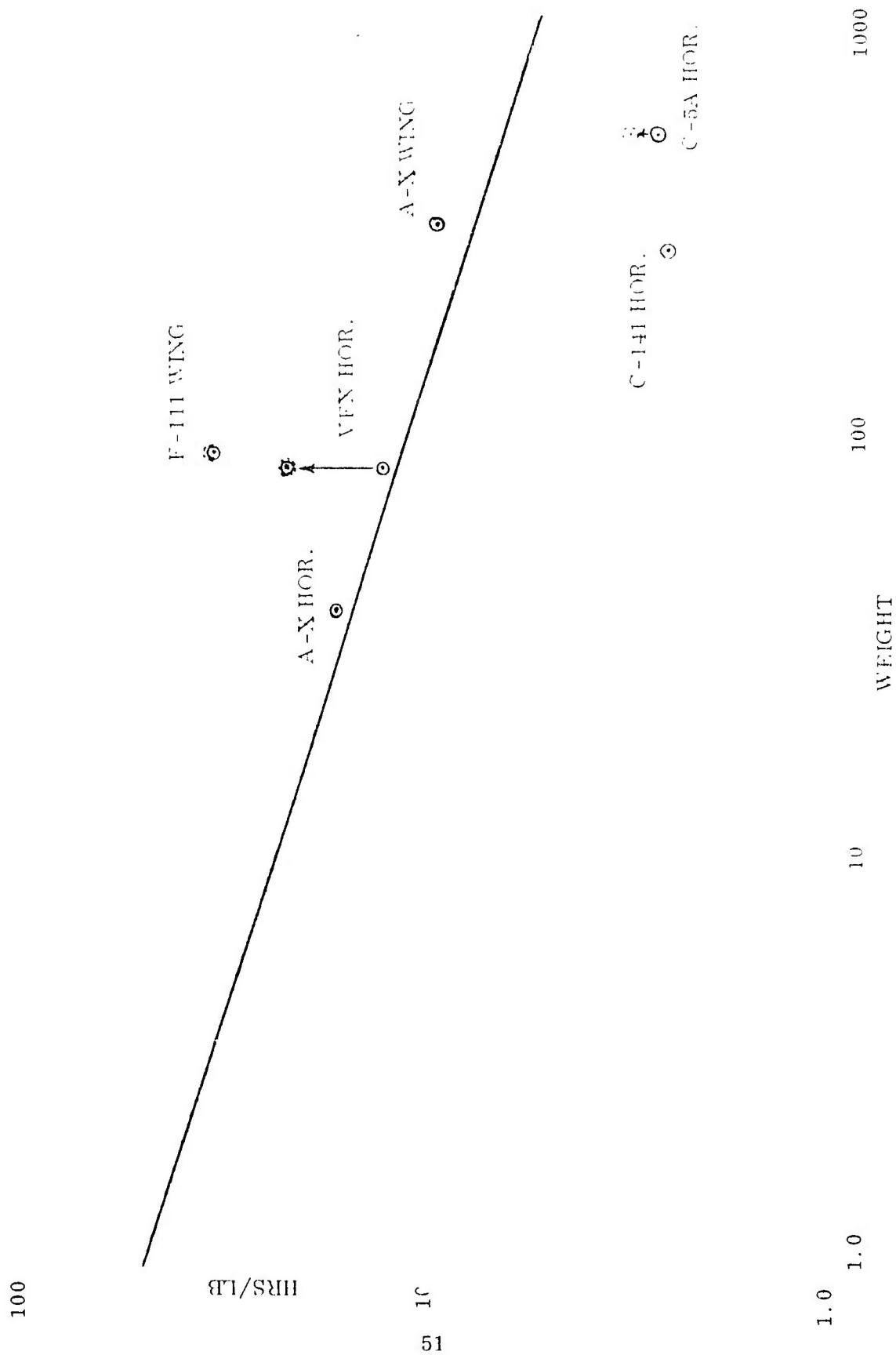


Figure 26. Normalized Data - Rib Detail Fabrication.

determinable value.

This assumption is based on empirical evidence, the results of several independent, internal studies. The same observation and reported value has occurred in external studies, References 5 and 6. Reference 5 cites the so-called ARCO formula, which observes that cost weight scaling is comparable to an 80% learning curve. This equates to an exponent value of 0.678 in the log-linear equational form,

$$y = aW^b$$

where

y = Aggregate cost in hours

a = The cost at $W = 1$

W = Weight of the components

b = Scaling exponent

The empirical observations gave a result of 0.67. On an hours per pound basis, i.e., dividing through by W,

$$W^b/W = W^{b-1}, \text{ or } b = -0.33,$$

the slope shown in Figure 26.

The value of y/W , at the point $W = 1$, is the estimating coefficient for detail fabrication labor for this particular hardware component. Similar plots of data and analyses to determine estimating coefficients were performed for rib, spars, covers, frames and longerons for wing, horizontal and vertical stabilizers, and fuselage for detail fabrication and subassembly labor. The results are given in Volume II where they have been interrelated to a description of CERs in turn related to the printouts of cost estimates.

To illustrate the organization of these estimating coefficients in the estimating method, Table 15 in Volume II is reproduced here as Table 4. This table shows

-
5. "Indices of Airplane Production Efficiency," Aircraft Resources Control Office, November, 1943.
 6. "Space Transport Cost Methodology." System Cost Office, The Aerospace Corporation, Contract No. F04701-70-C-0059, August, 1970.

Table 4. Cost Per Pound Factors
dHF_i Map

<u>DETAIL FABRICATION LABOR</u>		HF _i Code	Model Card		Model Card Value	Back-up Data Location
<u>WING</u>			Location			
Rib Spar Cover		HF1	F 31 1		51.0	F-1
		HF2	F 32 1		52.0	F-2
		HF3	F 33 1		11.0	F-3
<u>HORIZONTAL STABILIZER</u>						
Rib Spar Cover		HF1	F 100 1		51.0	F-1
		HF2	F 101 1		52.0	F-2
		HF3	F 102 1		11.0	F-3
<u>VERTICAL STABILIZER</u>						
Rib Spar Cover		HF1	F 151 1		51.0	F-1
		HF2	F 152 1		52.0	F-2
		HF3	F 153 1		11.0	F-3
<u>FUSELAGE</u>						
Frames Longerons Covers		HF1	F 201 1		100.0	F-4
		HF2	F 202 1		75.0	F-5
		HF3	F 203 1		32.0	F-6

cost per pound factors for detail fabrication labor for hardware components of the structural hardware elements. The model card in which the coefficient is used is indicated, the value of the estimating coefficient is shown and the location of the original data charts in the appendices of Volume II is given. Curve fit lines have not been drawn on these charts because significant changes may occur as the result of the acquisition of additional data.

It should be noted in connection with the estimating coefficients that the values given are at a weight of one pound. In use they scale down according to the weight of the component. Also they represent first unit cost, and in making comparison to quotes of cost per pound figures, unit number scaling must also be considered.

By reference to Figure 21, the CERs to which the costing concept described above apply can be seen. So far, only the CER for detail fabrication hours for the components of the structural box has been discussed. The remaining CERs using this concept are discussed below. The CER for subassembly labor for these components is of exactly the same form, only the baseline estimating coefficient, and of course, the input variables, differ. Comparisons of CERs can be made by reference to Appendix A.

CERs for detail fabrication and subassembly hours for secondary structure follow a form that is the same in both cases. For detail fabrication this is:

$$H_i = CB_i (WC_i) (WD_i)^{E_i}$$

where

H_i = Hours estimated

CB_i = Complexity factor

WC_i = Reference cost per pound

WD_i = Weight of component estimated

E_i = Scaling exponent

For subassembly, CB becomes CC, and WC becomes WF, and E becomes F, although the same assumption of constant slope is made.

It can be seen that this form is the same as that for primary structure, except that the complexity factor is not handled as a weighted factor. The costing concept used is exactly the same. Complexity factors are developed by analogy, and available

factors are summarized in Tables 25 and 26 in Volume II for detail fabrication and subassembly, respectively.

The explanation of the procedure for developing complexity factors relies on material from Volume II. Figure 27 is the first page from Table 25 of Volume II and shows complexity factors for detail fabrication for aerodynamic surfaces leading edges. Three types of data have been used in developing these factors:

- a. Historical cost data.
- b. Proposal cost data.
- c. Special Industrial Engineering analyses.

The leading edge will be used to illustrate.

The A-X wing and the A-X and VFX horizontal stabilizers represent proposal data. The remaining points for aluminum and the B-58 data point represent historical data. The data points for fibreglass and boron aluminum for Model 880 and Model 990, representing simple and complex types of leading edges, were developed by Industrial Engineering studies. An example of this data is shown in Figures 28 and 29. A plot of all data is shown in Figure 30. Complexity factors are determined as the ratio between a selected baseline estimating curve defined by the log-linear equation form defined above, with $CB = 1$:

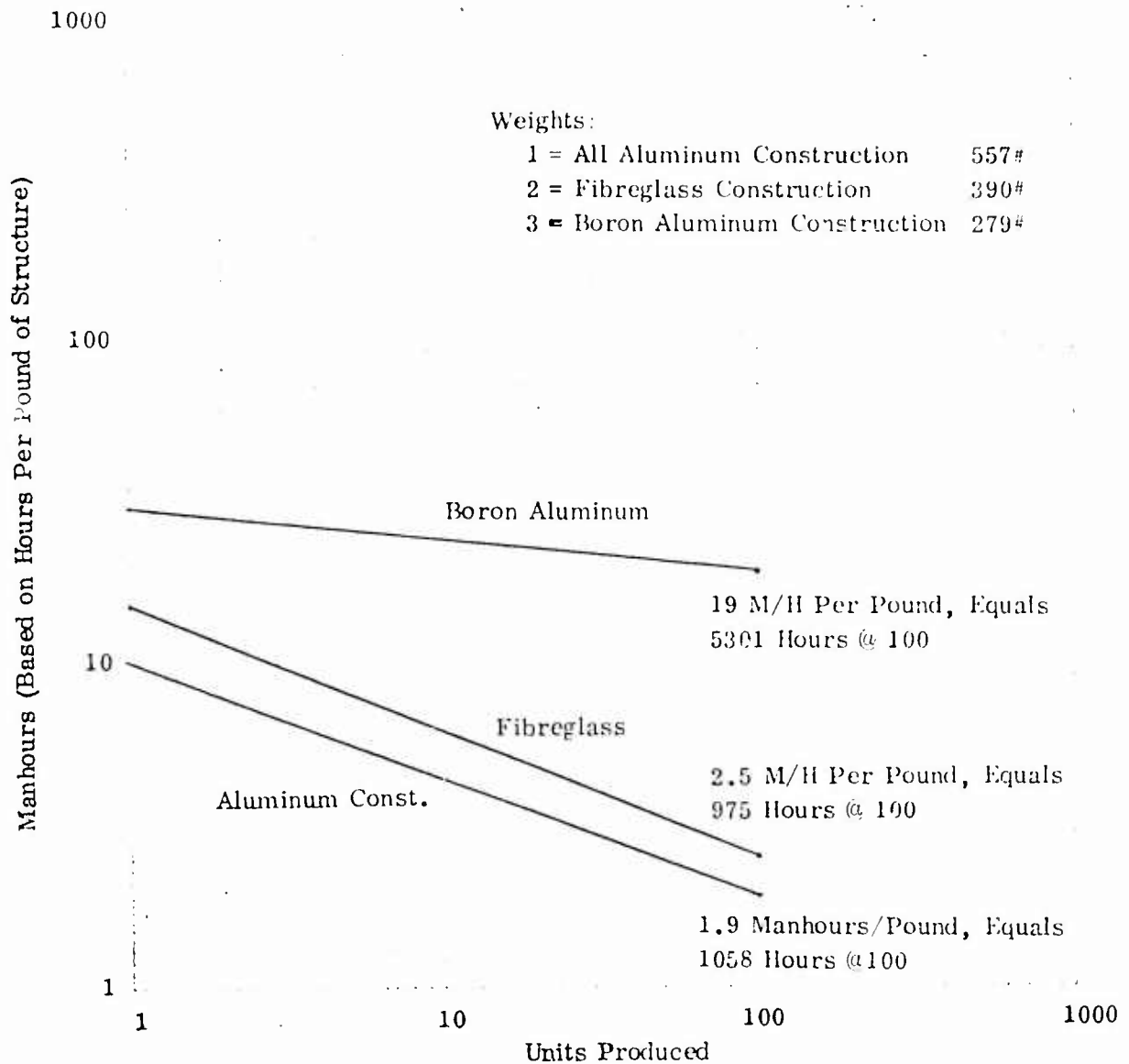
$$H_i = (WC)(WD)^E$$

As before $H_i = WC$ baseline cost per pound where $WD = 1$, assuming the same constant value for E . In this case the selected reference was the A-X horizontal stabilizer. With this as a reference, the baseline estimating curve can be drawn as shown in Figure 31. This then provides the basis for calculating complexity factors. Before proceeding to that, though, a word about how the data was plotted from Figures 28 and 29 to Figure 30.

The data in these figures is for combined detail fabrication and subassembly for a structure similar to the Model 880 in one case and the Model 990 in the other. Estimated weights of these structures are shown. At unit one, Figure 28 shows hours per pound by material as: aluminum, 10 hours/lb; fibreglass, 15 hours/lb; and boron aluminum, 30 hours/lb. The ratio between fabrication and subassembly is approximately 53% and 47%, respectively.

CONSTRUCTION INFORMATION	TYPE OF MATERIAL					
	Aluminum	Fiber- Glass	Boron Aluminum	Graphite Epoxy	Aluminum Honeycomb Sandwich	Titanium Steel
LEADING EDGE: Reference A-X Horizontal Stabilizer Model 880 Type (simple) Model 990 Type (complex) VFX Horizontal (supersonic) A-X Wing C-141 Horizontal B-58	1.0					
	1.0					
	0.76	1.0	1.8			
	0.87	1.5	2.2			
	1.25					
	1.70					
	1.47				1.75	
TRAILING EDGE: Reference Model 880 Type (simple) Model 990 Type (complex) VFX Horizontal C-5A Horizontal C-141 Horizontal B-58 (Honeycomb)	1.0					
	1.4					
	1.6	2.8	3.5	5.1	1.93	
	2.1					
	1.4					
	0.75					
						4.0
AILERONS (ELEVONS): Reference A-X Wing Model 990 Type (complex) B-58 (Honeycomb)	1.0					
	1.0					
	1.0		2.24	2.6	1.2	
						4.5

Figure 27. Secondary Structure Detail Fabrication Complexity Factor Examples.

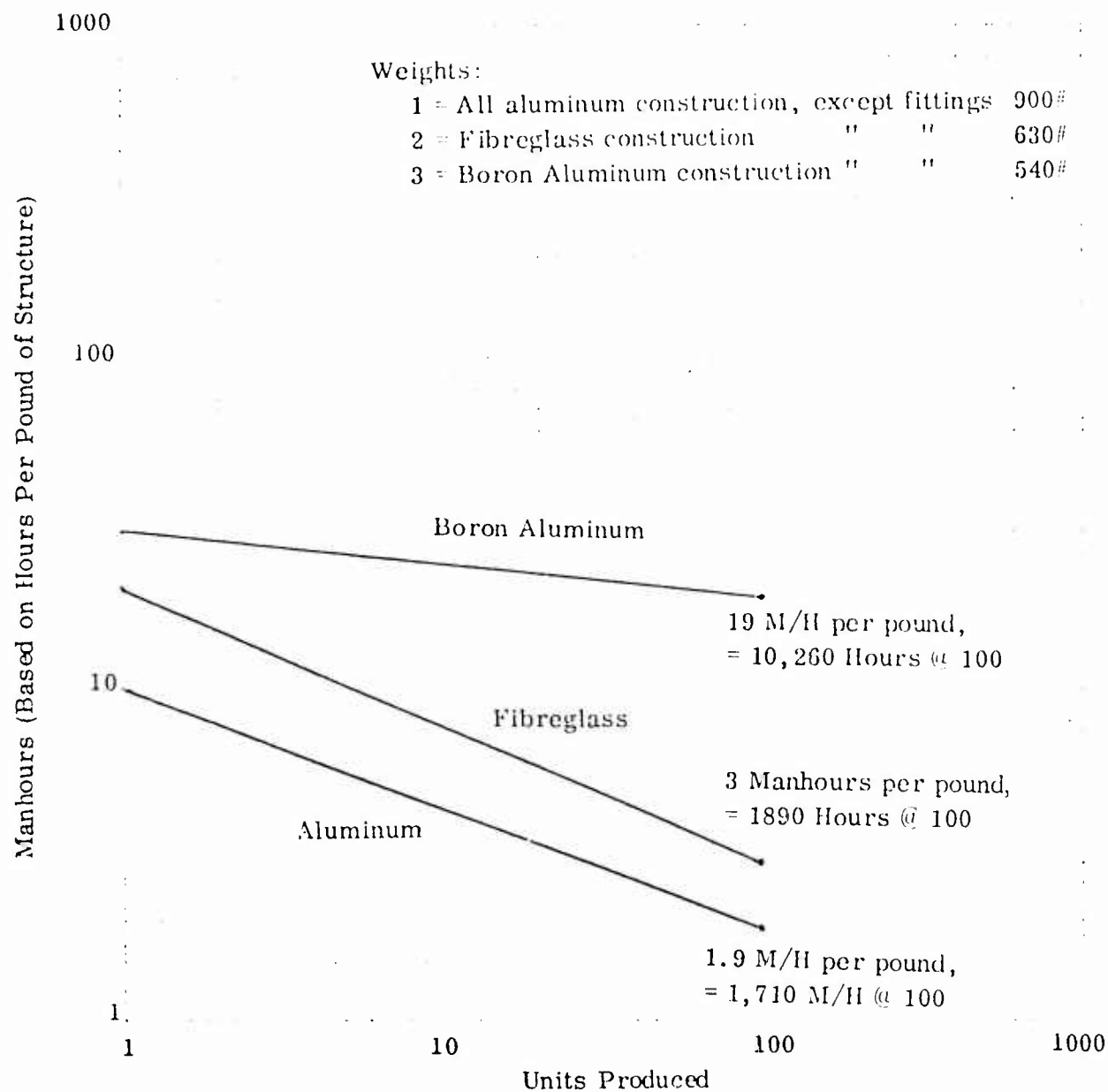


Notes: This is a simple structure assembly consisting of skins, doublers, frames, and is riveted. The assembly is tapered from inboard to outboard in straight elements. Design is similar to Convair 880.

The aluminum structure will experience a 78% learning curve. The fibreglass structure will experience a 88% learning curve. The Boron aluminum structure will experience a 92% learning curve. The last two flat curves are due to requirements for fixed cycles (cure/layup). Tolerance limitations which result in a higher rejection/rework rate hence higher costs.

This assembly data is applicable to vertical and horizontal stabilizer assemblies where no rain erosion or antenna provisions are included.

Figure 28. Wing Leading Edge Assembly.



Note: This is a complex structure assembly with a leading edge slat and associated mechanisms included. Similar to the Convair 990 assembly.

Figure 29. Wing Leading Edge Assembly.

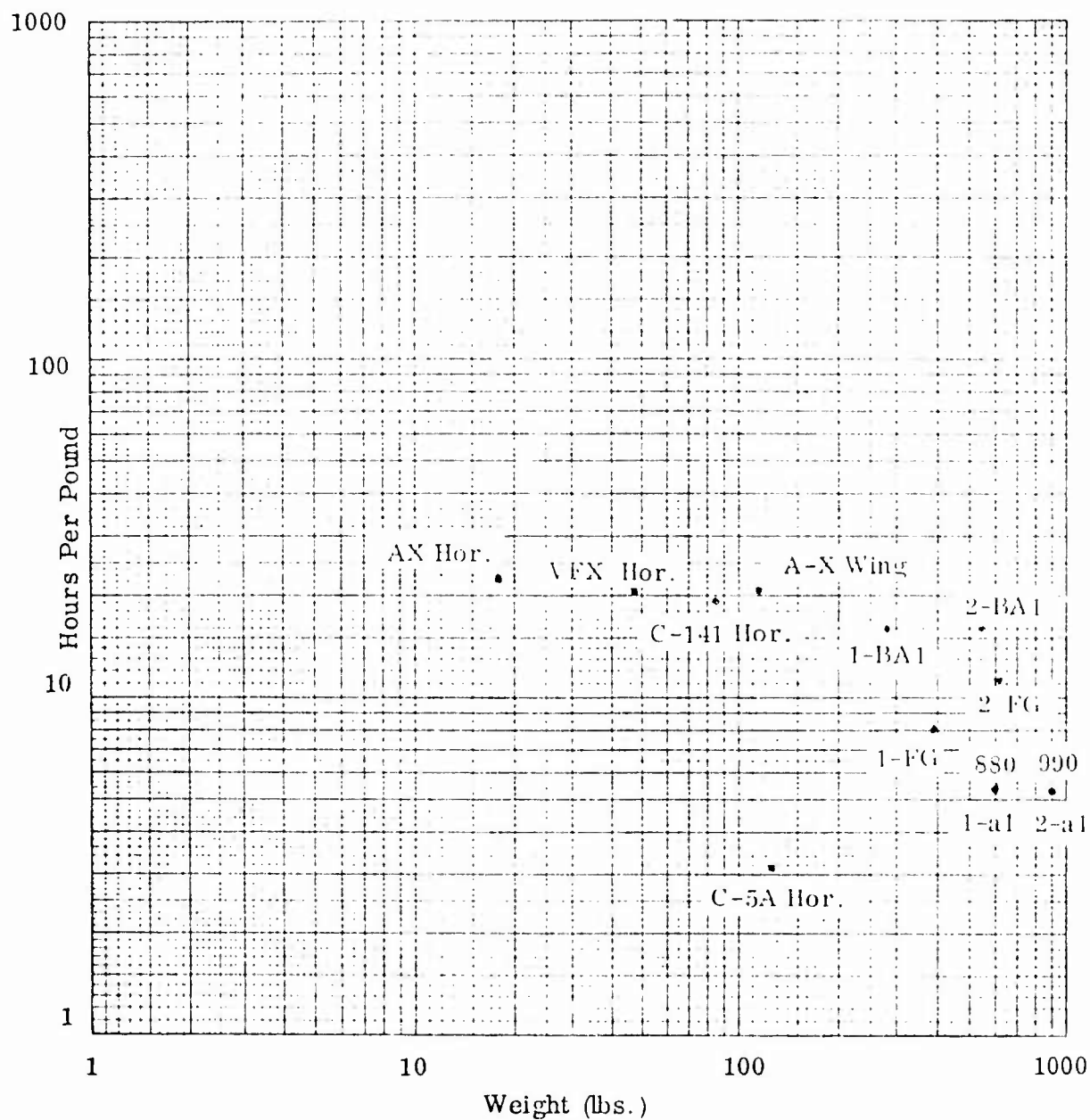


Figure 30. Leading Edge Detail Fabrication
Hours Per Pound Against Weight.

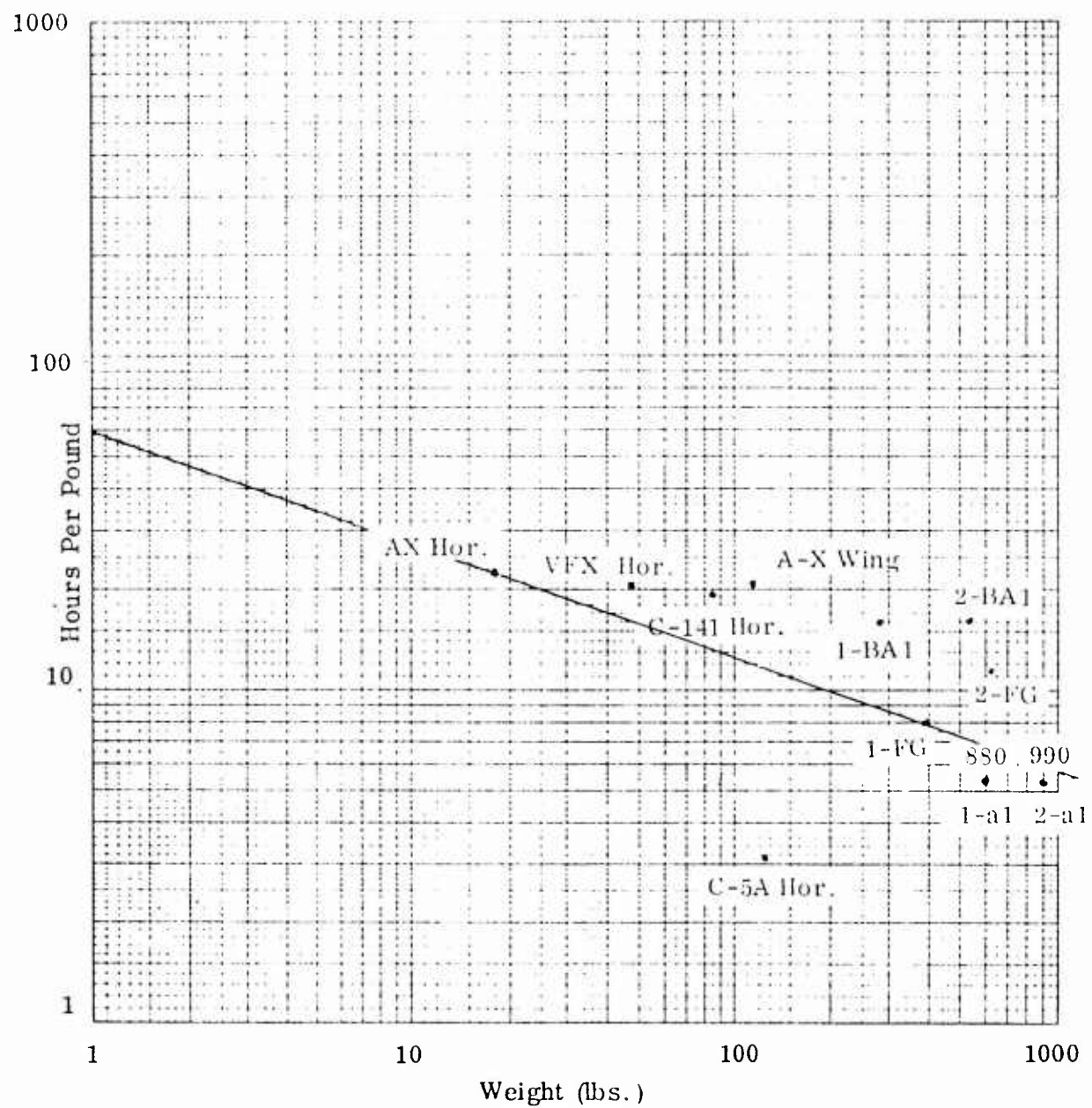


Figure 31. Leading Edge Detail Fabrication
Hours Per Pound Against Weight.

This gives:

	<u>Aluminum</u>	<u>Fibreglass</u>	<u>Boron Aluminum</u>
Fabrication (hours/lb)	5.3	8	16
Component weights (lbs)	557	390	279

These points are plotted on Figure 30 and labeled 1 - al for aluminum, 1 - FG for fibreglass, etc.

Figure 29 shows hours per pound by material as: aluminum, 10 hours/lb; fibreglass, 20 hours/lb; boron aluminum, 30 hours/lb.

This gives:

	<u>Aluminum</u>	<u>Fibreglass</u>	<u>Boron Aluminum</u>
Fabrication (hours/lb)	5.3	10.7	16
Component weights (lbs)	900	630	540

These points are plotted on Figure 30 and labeled 2 - al, etc.

Complexity factors are obtained by dividing a data point by the reference line values at the same weight. The resulting complexity factors are shown in Figure 27. This procedure was applied to obtain factors for the remainder of the secondary structure components for subassembly as well as detail fabrication.

The above discussion has covered CERs for cost outputs labeled 1 and 2 in Figure 21. A third type of CERs involves those for structural box assembly. For cost modeling purposes this task is defined as the assembly of the components making up the structural box or primary structure of the hardware element being estimated. The CERs used relate to basic processes of assembly driven by dimensional data.

A series of seven CERs are used for estimating structural box assembly (or as it is titled, Basic Structure Major Assembly Labor). These CERs are listed in Appendix A under the number 3 for the Figure 21 Reference and identified by the Volume II equation numbers of 3, 4, 5, 6, 7, 8, and 9. The set consists of the following factory labor representations:

- a. Transporting and Positioning - Aero Surfaces or Fuselage (3)
- b. Panel Fit and Trim - Aerodynamic Surfaces (4)
- c. Panel Fit and Trim - Fuselage (5)

- d. Assembly Clamp and Layout - Aero Surfaces or Fuselage (6)
- e. Hole Drilling - Aero Surfaces or Fuselage (7)
- f. Finish Operations - Aero Surfaces or Fuselage (8)
- g. Fastener Installation - Aero Surfaces or Fuselage (9)

The same set of equations are used for aerodynamic surfaces and fuselage. The only difference between b. and c. above is in the dimensions that are used. The basic CER forms were derived during the feasibility study, and the derivation was reported in Reference 1. Values for the various costing factors have been developed and are reported in Volume II. As an example of the results, Table 24 from Volume II is reproduced herein as Table 5. The value of the estimating factor is shown, as well as the location of the back-up data and the model card wherein the factor is used. Inputs to this equation set consist of the factors in Table 5 (Vol. II, Table 24), factors for type of fastener as provided in Table 23, Volume II, and inputs from the APAS program.

The fourth type of CER, as indicated in Figure 21, is Secondary Structure Major Assembly Labor. These CERs are listed in Appendix A as "Figure 21 Reference No. 4," equations (12) and (13) for Aerodynamic Surfaces and (14 and (13) for Fuselage. The CER for the assembly task is different in each case. Equations (12), along with (13), was developed during the feasibility study and is reported in Reference 1. The dimensional aspects of this CER were not suited to the fuselage and so equation (14), based on weight, is used for fuselage secondary structure major assembly.

The fifth CER grouping is for Structural Material for Primary Structure, equation (16). This CER is carried forward from the feasibility study but expanded to provide for consideration of three different types of material or construction in a given design to parallel that capability in the labor CER. The idea of a scaling of material cost with weight is based on empirical evidence, for example, Appendix H, Figure H-2, Volume II.

The sixth CER grouping identified in Figure 21 is for Structural Material for Secondary Structure, equation (17). This CER is of exactly the same form as the one above except that, paralleling the labor CER for secondary structure, only one type of material and construction is handled.

CER types 7 and 8 for Basic Structure and Component Assembly Material, equations (18) and (19) are each of the same form. They are based on labor hour factors, modified by the fastener type and related to the corresponding labor hours.

CER type 9, equation (15), simply represents the application of a percentage factor to the preceding labor subtotal. Type 10 and 11 are also percentage factor

Table 5. Structural Box and Basic Structure Major Assembly Factors -
Map and Factor Values.

	HSA1		HSA2		Q		HT	
	Model Card Location	Value	Model Card Location	Value	Model Card Location	Value	Model Card Location	Value
Wing Box	F 16 1	.2	F 15 8	2.0	F 15 8	.95	F 16 2	1.216
Horizontal Stab. Box	F 17 1	.2	F 15 9	2.0	F 15 9	.95	F 17 2	1.216
Vertical Stab. Box	F 18 1	.2	F 15 10	2.0	F 15 10	.95	F 18 2	1.216
Fuselage	F 22 3	.2	F 22 2	2.0	F 22 2	.95	F 22 4	1.216

	IHL		R		IID		IIE	
	Model Card Location	Value	Model Card Location	Value	Model Card Location	Value	Model Card Location	Value
Wing Box	F 16 3	1.238	F 15 1	.95	F 16 4	.557	F 16 5	.810
Horizontal Stab. Box	F 17 3	1.238	F 15 4	.95	F 17 4	.557	F 17 5	.810
Vertical Stab. Box	F 18 3	1.238	F 15 7	.95	F 18 4	.557	F 18 5	.810
Fuselage	F 22 5	1.238	F 22 1	.95	F 22 6	.557	F 22 7	.810

	HFI		Back-Up Data Location			
	Model Card Location	Value	HSA1	F-13	HT	F-14
Wing Box	F 16 6	.970	-	-	-	-
Horizontal Stab. Box	F 17 6	.970	HSA2	-	-	-
Vertical Stab. Box	F 18 6	.970	Q	-	-	-
Fuselage	F 22 8	.970		F-13	R	F-13
					HFI	F-14

applications. The first is equation (20) for Primary Assembly Hours as defined in Appendix A. The second is equation (21) for Major Mate Hours also defined in Appendix A.

2.2.4.2 Recurring Production Costs. Figure 32 is marked to identify in terms of output, the groupings of CER forms used to estimate recurring production costs. The explanation is simple since only two types are involved, aside from the application of labor rates to convert hours to dollars, which is excluded. The forms are:

- a. A log-linear unit learning curve projection.
- b. A percentage factor application or cost-on-cost form.

The first, shown in Appendix A, Equation (22), is of the following form:

For each unit in the series⁷:

$$y_i = a x_i^b$$

where

y_i = cost of the i^{th} unit

x_i = cumulative unit number

a = cost of the first article

b = slope

For the summation of units:

$$Y_n = a \sum_{i=1}^n x_i^b$$

7. J. W. Noah and R. W. Smith, Cost-Quantity Calculator, RM-2786-PR, Rand Corp., January 1962.

WING RDT&E COSTS TO

WING

17.28.86. 01/03/75

TOTAL LABOR HOURS TOTAL COST \$

DETAIL PART HOURS	SUB-ASSY HOURS	MAJOR ASSY HOURS	PRIM-ASSY HOURS	MAJOR RATE HOURS	MATL COST \$	TOTAL LABOR HOURS	TOTAL COST \$
42721	9174				315759		
82734	57229				737573		
103404	71612				1291437		
		372554			1723372		
224512	140115	372554			4048751		
1477416	209356	234323					

STRUCTURAL BOX SUB-TOTALS (1)

SECONDARY STRUCTURE

DETAIL PART HOURS	SUB-ASSY HOURS	MAJOR ASSY HOURS	PRIM-ASSY HOURS	MAJOR RATE HOURS	MATL COST \$	TOTAL LABOR HOURS	TOTAL COST \$
45244	45127				176393		
22526	22009				54199		
36606	211424				371644		
75551	67335				247777		
53733	47027				111454		
11041	22340				53470		
14110	30476				252645		
133779	83257	277881			395127		
					855515		

SECONDARY STRUCTURE SUB-TOTALS (2)

DETAIL PART HOURS	SUB-ASSY HOURS	MAJOR ASSY HOURS	PRIM-ASSY HOURS	MAJOR RATE HOURS	MATL COST \$	TOTAL LABOR HOURS	TOTAL COST \$
743914	547515	277941			2506355		
4505144	3643367	1747873					
398316	654430	651445			6553116		
42316	67541	65365			655312		
159870	76777	71542	205713	122353	7203423		
531363	475326	451241	1293973	645945			

TOTALS 2.0001 10.1155 25.3240

Figure 32. Wing RDT&E Costs.

By definition, the learning curve is expressed as a decimal percentage meeting the following condition:

$$S = \frac{a (2x)^b}{a x^b} = \frac{(2x)^b}{x^b} = 2^b, \text{ or}$$

$$b = \frac{\ln S}{\ln 2}$$

where

S = the decimal percentage

Equation (22) may be used for segmented learning curves if synthetic first unit costs are calculated external to the model.

The second form is the same as equations (15), (20) and (21).

2.2.4.3 Nonrecurring Design and Development Costs. Figure 33 is marked to identify the CER groupings used to estimate nonrecurring design and development costs. In this categorization as before, summations, as of previously estimated hours, and the conversion of hours to dollars are omitted. The CER forms that are referred for each grouping are numbered and described in Appendix A.

Basic Structure Design Engineering Hours

The first CER form is based on Equation (23) as shown and defined in Appendix A. It is:

$$DEH_i = EH_i (WAMPR_i)^{EE}$$

where

DEH_i = The series of engineering hours by hardware element.

EH_i = Empirically derived estimating coefficient by hardware element.

$WAMPR_i$ = AMPR weight of the hardware element being estimated.

EE = Scaling exponent of engineering hours to weight.

The data from which this CER form is derived is included in Appendix I, Volume II,

AEROSPACE VEHICLE STRUCTURAL COSTS NONRECURRING DESIGN AND DEVELOPMENT COSTS

17-26-46. 01/09/75

	WING HOURS	WORT HOURS	VERT HOURS	FUSE HOURS	NADE HOURS	LOG GEAR HOURS	SUB-	
							TOTAL HOURS	DOU- LAR COSTS
① →	.152		.029	.201	.191	.379	.652	4.277
							.750	4.919
							1.402	9.685
								③

BASIC STRUCT DESIGN ENGR
CONFIGURATION DESIGN ENGR
ENGINEERING MATERIAL
TOTAL TRADE STUDY ENGR

	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪
④ →	8.893	.724	6.329	4.070	.049	17.854	4.337	139.229
						22.241	7.142	45.330
						7.658	7.800	22.241
						.445	.445	9.179
							1.342	33.229
								220.134

BASIC TOOL MFG HOURS
PATE TOOLING MFG HOURS
TOTAL TOOL MFG
BASIC TOOL ENGRS HOURS
PATE TOOL ENGRS HOURS
TOTAL TOOL ENGRS
MFG LEVEL - PLANT ENGR
TOOLING MATL & OTHER DOLLARS
MANUFACTURING SUPPORT DOLLARS
QUALITY CONTROL
TOTALS

Figure 33. Nonrecurring Design and Development Costs.

Figures I-1 through I-6. Figure I-1 is reproduced here as Figure 34 for the purpose of illustration. The hardware elements covered are the same as for manufacturing. The estimating coefficient is the value of DEH where WAMPR = 1 lb on the projection of a "best fit" curve. A constant scaling exponent is tentatively assumed.

The present form of the CER does not provide for complexity. Consideration was given to redefining the best fit curve as a reference and modifying EH by a complexity factor. Two problems were evident: the paucity of data and the fact that relationships do not suggest themselves in the case of design engineering. A format has been established for further cost data collection to improve the first situation and to provide for additional data analyses to attempt to quantify complexity. Alternate values of EH can be introduced based on analogy to the given data points.

Configuration Design Engineering Hours

This CER form is based on Equation (25) and consists simply of the application of a percentage factor to the basic structure design engineering hours. The factor is based on historical data given in Volume II, Appendix I.

Engineering Material

The third CER form is again a cost-on-cost percentage factor. A value of 0.15 based on available cost histories is programmed into the present model.

Basic Tool Manufacturing Hours

CER form 4 is based on Equation (28) defined in Appendix A. It is of the following form:

$$BTMH_i = TMF_i (WAMPR_i)^{ET}$$

where

$BTMH_i$ = Basic tool manufacturing hours by hardware element.

TMF_i = Empirical estimating coefficient by hardware element.

ET = Scaling exponent of tool manufacturing hours to weight.

The back-up data for this CER derivation is included in Appendix I, Volume II, Figures I-7 through I-11. Figure I-7 is reproduced as Figure 35 to illustrate the discussion. This equation is the same in form as Equation (23) for engineering. The term TMF is handled differently from the term EH. A rationale for complexity variations is discernible in the case of tool manufacturing. This is illustrated in

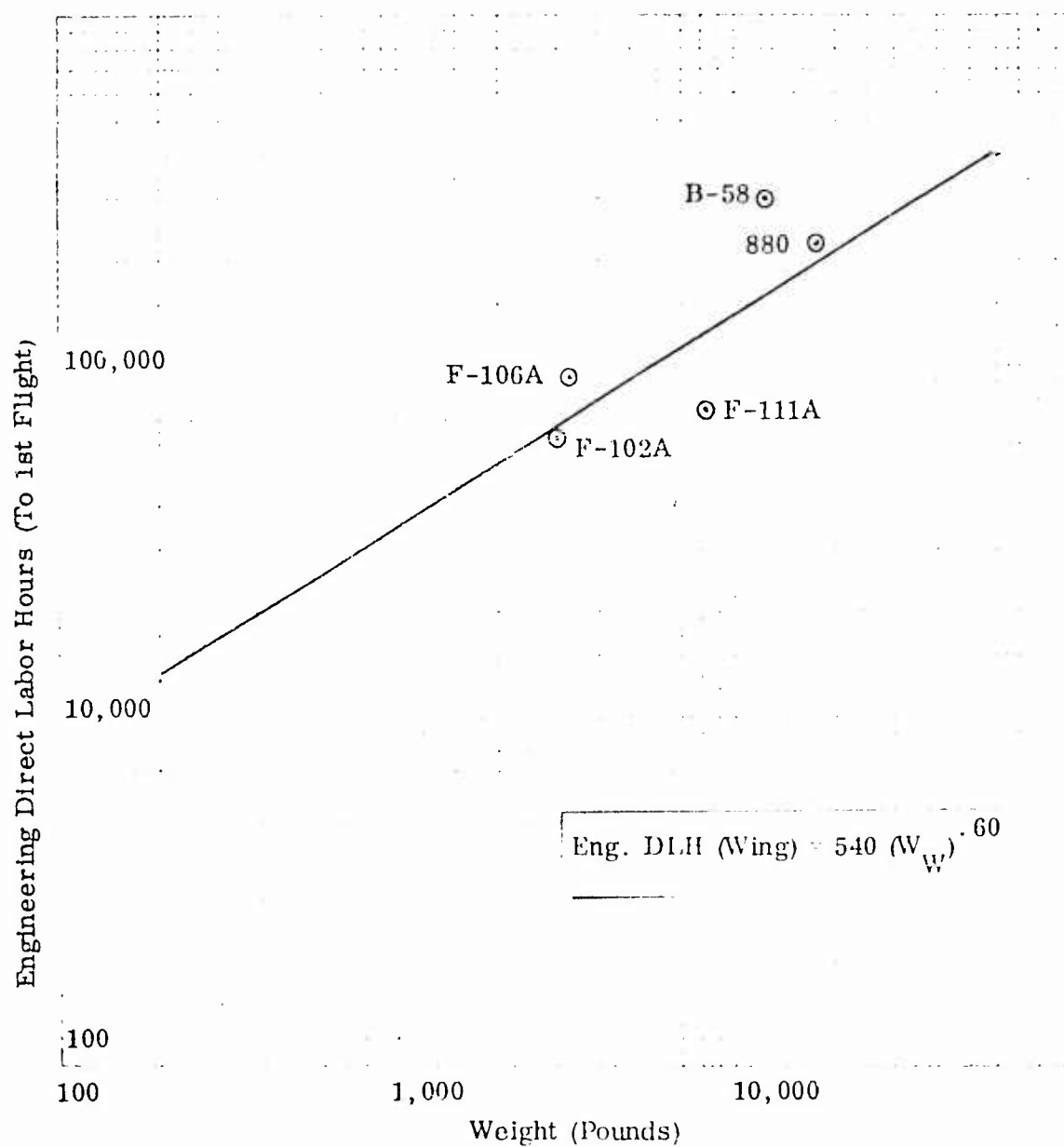


Figure 34. Wing Engineering Cost Estimating Relationship.

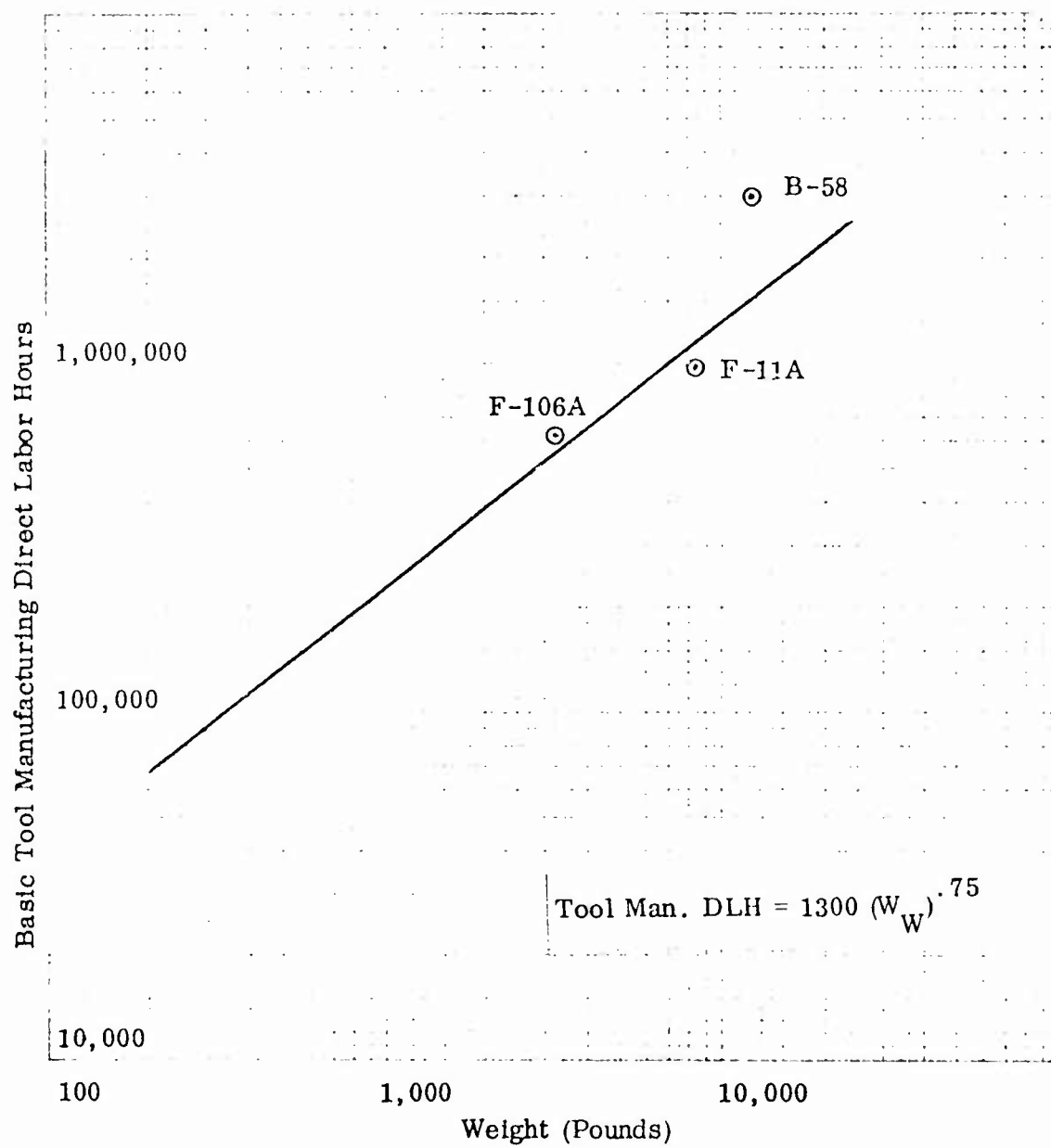


Figure 35. Wing Tool Manufacturing Cost Estimating Relationship.

Table 6 (Table 40, Volume II). This table is baselined to the data plotted in Figure I-7 through I-11 (Volume II) by defining the best fit curve as "regular supersonic" with a "complexity factor" of 1.0. Complexity is built into the table as indicated by the values given in the complexity column. This matrix is subject to verification as data is accrued.

Rate Tool Manufacturing Hours

This fifth form is based on Equation 29 as defined in Appendix A. The form of this CER is suggested by Rand Corporation studies, Reference 8. The value of the production rate exponent, ER, has been adjusted based on contractor experience. Also, some ambiguity occurs in attempting to define a base for a one-unit per month production rate.

Basic Tool Engineering Hours

Form 6 is based on taking a percentage factor of basic tool manufacturing hours.

Rate Tool Engineering Hours

Form 7 is based on taking a percentage factor of rate tool manufacturing hours.

Manufacturing Development and Plant Engineering Hours

The eighth CER form, as indicated in Figure 33, is based on a percentage factor: the rates of manufacturing development and plant engineering to total tool manufacturing hours.

Tooling Material and Other Dollar Costs

CER form 9 is a cost-on-cost form: a per hour allowance on total tool manufacturing hours.

Manufacturing Support Dollar Costs

CER form 10 is based on a percentage factor based on manufacturing experience.

-
8. G. S. Levenson and S. M. Barro, Cost Estimating Relationship for Aircraft Airframe, RM-4845-PR, Rand Corp., December 1965.

Table 6. Tool Manufacturing Hours CER Coefficients.

TMF Value	Complexity	Wing	Horizontal Stabilizer	Vertical Stabilizer	Fuselage	Nacelle	Landing Gear
	Simple Design - Subsonic (.35)	455.	260.	210.	620. (.5)	435.	--
	Regular Subsonic (.50)	650.	375.	300.	745. (.6)	620.	--
	Complex Subsonic (.65)	845.	490.	390.	930. (.75)	815.	--
	Simplified Design - Supersonic (.85)	1105.	940.	510.	1120. (.9)	1055.	--
	Regular Supersonic (1.0)	1300.	750.	600.	1240.	1240.	--
	Complex Supersonic (1.4)	1820.	1050.	840.	3470. (2.8)	1735.	--

Quality Control Hours

CER form 11 is based on taking a percentage of the configuration design engineering hours plus a percentage of total tool manufacturing hours.

2.2.4.4 Recurring Airframe Production Costs (Summary). Figure 36 identifies the CER groupings used to provide the recurring airframe production cost summary. It is based on test case results in which only one production quantity is involved. The calculations are the same for each quantity so only one needs to be explained. The first, RDT&E, is used. Again the process of converting from hours to dollars is omitted. The reference to equation numbers is from Appendix A, which gives a listing of CERs, their form and definition. Sustaining engineering hours, sustaining tooling hours and primary assembly and major mate material are items of cost that are introduced for the first time. As indicated in Figure 36, six different CER forms are involved:

Sustaining Engineering and Tooling Hours

These two CER forms are taken from the Rand methodology, Reference 8. This approach agrees reasonably well with contractor data.

Manufacturing Summary: Detail Fabrication, Subassembly and Assembly Labor and Material Cost

This CER form is used to provide a summarization for each hardware element for each of the above cost categories. These three types of cost are handled in the same way as described for the progress curve projection procedure used for recurring production costs for structural elements, except that for RDT&E units the following equation is used.

$$\text{Cost estimated} = P1 \sum_{i=1}^{P2} U_i^x$$

where

P1 = First unit cost

P2 = The number of RDT&E Units

U = Unit number

x = $\frac{\ln P3}{\ln 2}$, and

P3 = Learning expressed as a decimal fraction

AEROSPACE VEHICLE STRUCTURAL COSTS
RECURRING AIRFRAME PRODUCTION COSTS (SUMMARY)

17.20.66. 01/09/75

ROUTE	WING		MORT		VERT		FUSE		NAZE		LOG		SUB-		DOL		PROD
	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	HOURS	GEAR	GEAR	TOTAL	HOURS	LAR	COSTS	UNITS
SUSTAINING ENGRG SUSTAINING TOOLING MINOR TOOLING																	30
TOTALS																	

PROCUREMENT ARTICLES																	
SUSTAINING ENGRG																	
SUSTAINING TOOLING																	
MINOR TOOLING																	
TOTALS																	

Figure 36. Recurring Airframe Production Costs (Summary).

The estimates for each hardware element are summed to give an appropriate labor or dollar total.

Primary Assembly and Major Mate Hours Quality Control Hours

These are identified as forms 4 and 5 on Figure 36. Each is a summarization of a previously estimated set of hours with the application of a percentage factor.

Primary Assembly and Major Mate Material

CER form 6 supplies an estimate of production material for support of primary assembly and major mate as related to individual hardware elements. The estimate is made as a percentage of structural material.

2.3 DEVELOPMENT OF THE FUSELAGE-NACELLE-LANDING GEAR MODULE

Study activity since the interim report has been primarily concerned with extension of the estimating method into the areas of the fuselage, nacelles and landing gear, with whatever modifications that were necessary for such extension. Activity included the following items for fuselage and the other structure:

- a. Development of additional cost data.
- b. Derivation of first-unit and nonrecurring CERs.
- c. Development of complexity factors.
- d. Development of baseline estimating coefficients.
- e. Development of appropriate supporting structural and weight synthesis programs
- f. Development of cost estimating methodology for other basic structure: nacelles and landing gears.
- g. Modifications to the cost model computer program.
- h. The estimating of test cases.

This section of the report provides a statement of the approach to that portion of the study. Other sections of the report include the results of this activity since they discuss the total methodology. In the sections above all aspects of the method were described. In the sections that follow this is also true. The cost model computer program describes the entire program including the fuselage routines. The section on design synthesis and weight analysis supporting programs provides a discussion of each of the programs involved. The method demonstration is also, of course, related to the entire method.

2.3.1 DEVELOPMENT OF FUSELAGE COST DATA. The total data sample from which fuselage cost data was collected and analyzed consisted of the following aircraft:

F-111A	VSX (Estimated)
B-58	A-5A
AX (Estimated)	T-2A
F-106	
F-102	

F-106 and F-102 data availability was limited to production data. B-1, 747 and F-5E data, which were expected to become available from various Air Force Studies, have not yet become available. DC-10 data has not been cleared contractually for unlimited distribution. The possibility of obtaining C-141 and C-5 fuselage cost data from Air Force sources has not been developed. F-111A data consisted primarily of elements of the structure subcontracted to the Convair Division.

In addition to the available data, the results of special industrial engineering studies were utilized. These involved investigations of secondary structure components on the basis of a substitution of materials and determining the expected impact on cost. The results of these studies appears in Appendix G, Volume II, together with similar data for aerodynamic surfaces.

2.3.2 DERIVATION OF COST ESTIMATING RELATIONSHIPS. In the extension of method to the fuselage, nacelle and landing gear, as much of the aerodynamics surfaces methodology was retained as was possible. In certain instances changes were indicated, however. The following is a review of the CER structure indicating differences that arose. (Equation numbers are referenced to Appendix A)

First Unit Cost

Equations (1) and (2) for detail fabrication and subassembly labor were considered to be equally applicable to ribs, frames, spars, longerons and covers. In the series of equations for basic structure major assembly labor, equations (3) through (9), one equation required modification for estimating fuselage structure but this was merely to redefine inputs. In each case the computer program handles the matter of counting items of structure, e.g., right and left wing as opposed to only one fuselage. Equations (10) and (11) for detail fabrication and subassembly are used without change.

The CERs for component major assembly labor required modification. Equation (13) is used throughout but equation (12) is replaced by equation (14) for the fuselage (also the nacelle and landing gear). A suitable relationship to dimensional data could not be found in the case of the fuselage, and a CER based on weight was substituted. Structural material cost CERs for primary and secondary structure are used

throughout. This is also true of basic structure and component assembly material cost and primary assembly and major mate.

Recurring Production Costs by Structural Element

Since this series of estimates involves only the process of learning curve projection, application to fuselage components introduced no changes.

Nonrecurring Design and Development

This category involves basic structure design engineering hours, configuration design engineering hours, engineering material, basic tool manufacturing hours, basic tool engineering hours, quality control, and other support activities estimated at the subsystem level. The applicable equations are equations (23) through (39). (Note that those equations not mentioned in Appendix A are covered in Volume II.) No change in CER forms were involved, however, some CERs required the collection of additional data and the development of estimating coefficients. These were:

- a. Basic structure design engineering hours
- b. Configuration design engineering hours
- c. Basic tool manufacturing hours

Data collected for each is shown in Appendix I of Volume II.

Recurring Airframe Production Costs (Summary)

This category includes equations (40) through (45). No change in CER forms were involved.

2.3.3 DEVELOPMENT OF COMPLEXITY FACTORS. Additional complexity factor tables were developed for the expanded method for primary and secondary structure. For primary structure, these are Tables 10, 12, and 14 (in Volume II) for detail fabrication and Tables 17, 19, and 21 for subassembly. For secondary structure, all factors are combined in Table 25 for detail fabrication and Table 26 for subassembly. Development of complexity factors was accomplished in the manner described in Section 2.2.4.1. In the case of the fuselage, complexity factor development, in some cases, involved proprietary data that is not reproduced.

2.3.4 DEVELOPMENT OF BASELINE ESTIMATING COEFFICIENTS. The development of baseline estimating coefficients was also handled in the same manner as was described in Section 2.2.4.1. Data collected is shown in Appendix F of Volume II. Baseline factors are located and referenced in the same manner as in the previous method. Back-up data for fuselage factors are not as extensive as for aerodynamic

factors in the contractor's data base. Where data was lacking, estimates were made by analogy. The method does seek to identify the data collection format for future reference.

2.3.5 DEVELOPMENT OF SUPPORTING STRUCTURAL AND WEIGHT SYNTHESIS PROGRAMS. As can be seen from Figure 20, Input Development, technical inputs as opposed to costing factors are obtained primarily from the so-called supporting synthesis programs. These sources are as follows:

- a. Dimensional data from the APAS program.
- b. Estimates of primary structure weights using APAS theoretical weights and applying weight correlation factors.
- c. Estimates of secondary structure weights obtained from the secondary structure synthesis and weight analysis program.
- d. The program for development of aircraft fuselage, nacelle, and landing gear weights.

The dimensional data are for the most part throughput data to the APAS program. The second and third items were developed in connection with the aerodynamic surfaces and are discussed in Volume II of Reference 2. The fourth item was developed to support the extension of method to the fuselage, nacelles, and landing gears. Section V of this report is devoted to a discussion of these programs: a summary in the case of the first two and a detailed description (by means of Appendix C) in the case of the latter. A study of finite element synthesis as a substitute for the APAS program is also discussed.

2.3.6 NACELLE AND LANDING GEAR DEVELOPMENT. The extension of the estimating method to the nacelle and landing gear presented additional problems. In the first place, neither involves what for the purposes of this study has been classified as primary structure. The breakdown of components used for estimating purposes consists of the following structural elements:

Nacelles

Nacelle structure and covers
Pylons
Main landing gear door

Landing Gear

Brakes
Brake controls
Wheels

Tires
Oleos
Axles, trunnions, and fittings
Drag braces

Very little cost data was available for these breakdowns. First unit cost CERs for primary structure excluded both items. Secondary structure estimates were made in the same manner as for other structural elements. Methodology for estimating nonrecurring costs was simply an extension of the previously developed method.

2.3.7 COST MODEL COMPUTER PROGRAM MODIFICATIONS. The final resulting cost model computer program is described and discussed in Section IV. Addition of the fuselage, nacelle, landing gear capability required several modifications to the program created for aerodynamic surfaces. The program was, of course, expanded by the addition of elements. A major expansion was undertaken to add the capability for applying learning curves at the component level of detail. Several format improvements were introduced.

2.3.8 ESTIMATING TEST CASES. The B-58, A(X) and Model 880 fuselages were run as test cases in the development of the fuselage module. A series of APAS runs was made to provide the input data for the fuselage, nacelle and landing gear weights program, which was in turn run to provide weights data. Test case inputs and outputs for this program are shown in Appendix C. Resulting cost estimates were analyzed and used in evaluating baseline cost estimating factors. The computer printouts obtained are not reproduced in this report, but have been retained. These results are not particularly of current interest because of changes that have occurred both in the program and in the estimating coefficients.

2.4 FUTURE DEVELOPMENTS

An assessment of the potential for further development of the method has resulted from the study. Several additional studies suggest themselves:

- a. Extension of the cost data base (1) to provide data for missing components and (2) to extend the data base into advanced type structures.
- b. Further test and evaluation of the method for further familiarization and to eliminate program discrepancies.
- c. Improvements in certain specific cost estimating relationships in the areas of raw material costs, assembly modeling, commonality, and the treatment of advanced structures and composites.

- d. Modification of the estimating logic to provide for determining the sensitivity of recurring cost to production rate.
- e. Development of data to show variation in learning due to type of material and type of construction.
- f. Incorporation of additional calculations to provide a readout of the dollars/lb. and hours/lb. implication of a given estimate.
- g. Performance of additional estimating runs using the updated method to further calibrate estimating coefficients and to evaluate estimating capability.
- h. Operation of the cost model in conjunction with supporting synthesis programs to establish guidelines for using the combined programs in design-to-cost trade-off studies.

A cost data collection format has been established, and a number of ongoing studies arising out of the Air Force Flight Dynamics Laboratory's sponsorship of Advanced Development Program warrant monitoring. Continuing literature review and an interchange of data with other contractors are also possible sources of additional data.

This cost model has been developed in response to a recognized need for a cost model that was sensitive to variations in the materials and type of construction in a particular design. The need was in relation to trade studies to evaluate the impact on cost of using advanced technologies in structure and materials. More recently the Design-To-Cost approach in the acquisition of new weapon systems has increased the need for models of this type. The additional developments outlined above, including the experience gained from use, will greatly enhance the program.

SECTION III

AIRFRAME SYSTEM COST ESTIMATING METHOD

The rationale for having both a trade study and a system cost estimating method and the preliminary design applications visualized have been described in the previous sections. This section describes the system cost estimating method and its operation. The development of the system cost estimating method has been accomplished subsequent to the Interim Report. Limited study resources have been assigned to this task since primary emphasis has been given to development of the trade study methodology. The results of Independent Research and Development has been used in the development of the method, in particular References 9, 10, and 11.

The difference between the two methods in hardware elements covered is illustrated in Figure 37. This also illustrates the difference in meaning ascribed to the term "airframe" when used with respect to each method.

3.1 METHOD DESCRIPTION

A flow diagram of the system cost estimating method is shown in Figure 38. The basic elements of this method are essentially the same as was shown in Figure 8 for the trade study method. With changes indicated these are:

- a. Costs estimated (cost output).
- b. CER structure (estimating logic).
- c. Inputs and input organization.
- d. Input sources (input development).

-
9. R. E. Kenyon and R. J. Reid, "Aircraft Cost Estimating Relationship Improvements, Construction and Material Effect and New Data," GDC-ERR-1333, Convair Aerospace Division of General Dynamics, January 1972.
 10. R. E. Kenyon and J. M. Youngs, "Airframe Structure Cost Estimating Relationships and Expanded Cost Data Base," CASD-ERR-73-059, Convair Aerospace Division of General Dynamics, December 1973.
 11. R. E. Kenyon and J. M. Youngs, "Airframe Structure Cost Estimating Relationships," CASD-ERR-74-005, General Dynamics, Convair Division, December 1974.

WORK BREAKDOWN STRUCTURE	TRADE STUDY COSTING	SYSTEM COSTING
AIRFRAME		
Wing	X	X
Horizontal Stabilizer	X	X
Vertical Stabilizer	X	X
Fuselage	X	X
Nacelles	X	X
Landing Gear	X	X
Surface Controls		X
Fuel System		X
Furnishings & Equipment		X
Environmental Control		X
Hydraulics/Pneumatics		X
Electrical/Electronics		X
Instruments		X
Auxiliary Power		X
Engine-Associated Equipment		X
Avionics Installation		X
Airframe Assembly	X	X

Figure 37. Trade Study versus Systems Costing WBS Inclusions.

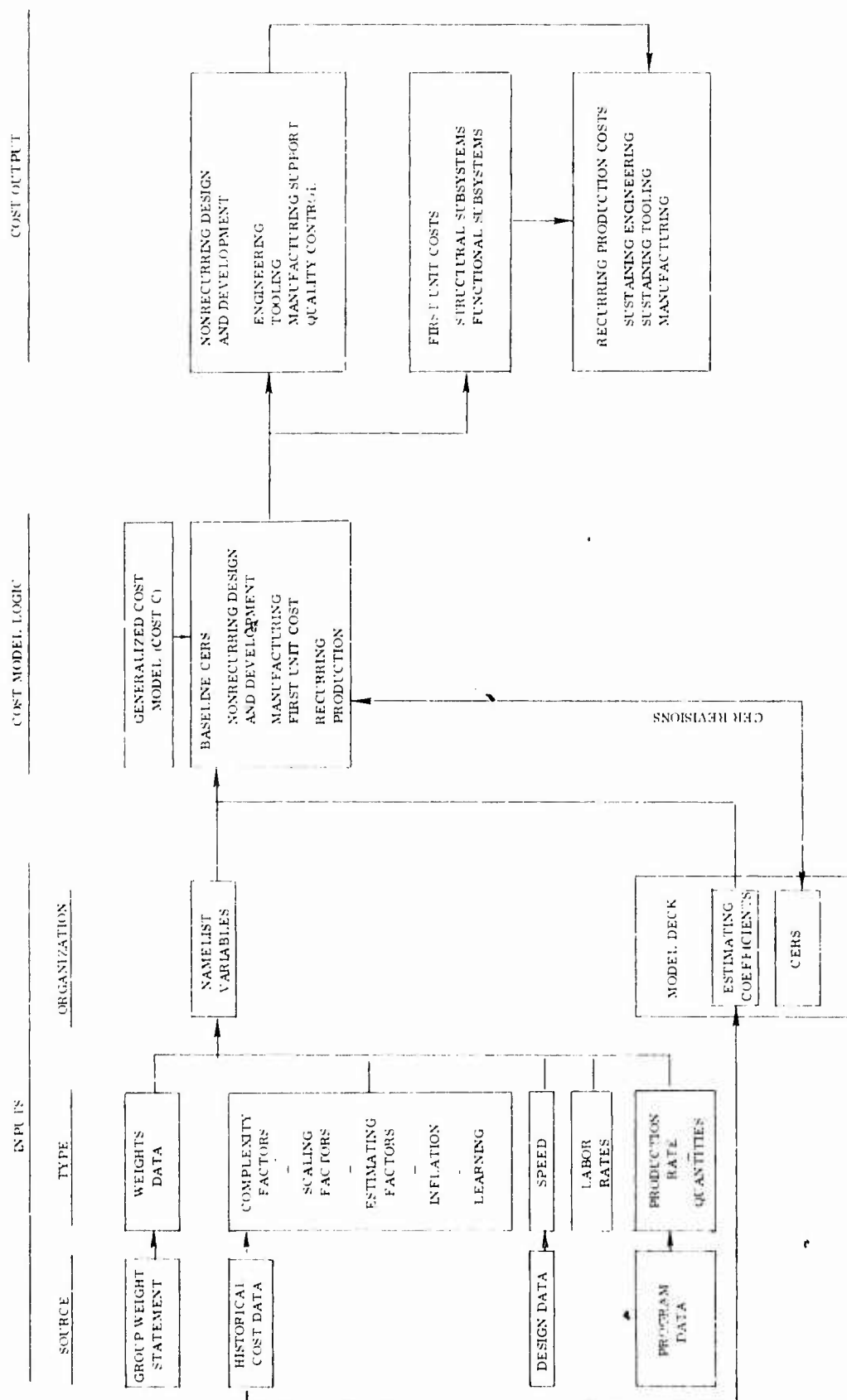


Figure 38. System Cost Estimating Method.

3.1.1 COSTS ESTIMATED. Costs are estimated in the categories of.

- a. Nonrecurring Design and Development Costs.
- b. First Unit Manufacturing Costs.
- c. Recurring Airframe Production Costs.

The breakdown by aircraft subsystems is illustrated in Figure 39. Recurring airframe production costs use the same breakdown as first unit costs. The cost output formats are illustrated in Figures 40, 41, and 42. The CERs used to produce these estimates are defined in the following section.

3.1.2 CER STRUCTURE. Cost definitions, CER forms, and inputs and input organization were described in Section 3 of Volume II. For completeness and ease of reference a list of the various CER forms used is also included in this volume as

	Engineering Direct Labor	Toof Mfg. Direct Labor	Manufacturing First Unit Cost
Structural Subsystems			
Wing	x	x	x
Horizontal Stabilizer	x	x	x
Vertical Stabilizer	x	x	x
Fuselage	x	x	x
Nacelles	x	x	x
Landing Gear	x		x
Functional Subsystems			
Surface Controls	x		x
Environmental Control System	x		x
Hydraulics/Pneumatics	x		x
Electrical/Electronics	x		x
Instruments	x	x	x
Auxiliary Power	x		x
Armament Provisions	x		x
Engine Associated Equipment	x		x
Fuel System	x		x
Avionics Provisions	x		x
Furnishings and Equipment	x		x
Support Engineering	x		

Figure 39. Airframe System Cost Estimating Structure.

B-52 TEST CASE
 USE OF DECIMAL MULTIPLIER UNIT IN MILLIONS
 AIRCRAFT VEHICLE AIRFRAME SYSTEM COSTS

NONRECURRING DESIGN AND DEVELOPMENT COSTS

12.43.54. 01/09/73

DECT OR CT LABOR ENGNG MAIL LABOR MAIL
 LABOR COSTS COSTS COSTS

ENGINEERING

BASIC STRUCTURE DESIGN ENGNG

WING .305
 HORIZONTAL STABILIZER .042
 VERTICAL STABILIZER .421
 FUSELAGE .382
 WHEELS .132
 LANDING GEAR

CONTOUR DESIGN ENGNG

2.027

EQUIPMENT DESIGN

ENGINE CONTROL .274
 ENVIRONMENTAL CONTROL SVS .187
 HYDRAULICS/PNEUMATICS .113
 ELECTRICAL .281
 INSTRUMENT .301
 AUXILIARY POWER UNIT .055
 AIRCRAFT SYSTEMS .047
 ENGINE ASSOCIATED EQUIP .112
 FUEL SYSTEM .101
 AIRCRAFT DESIGN .183
 ENGINEERING + EQUIP

TOTAL ENGNG LABOR
 30.761

5.122 30.117

Figure 40. System Cost Estimating - Nonrecurring Design and Development Costs.

[illegible]

3-21-61

[illegible]

Figure 40. System Cost Estimating - Non-recurring Design and Development Costs (Contd.).

APOLLO SPACE VEHICLE AIRBORNE SYSTEM COSTS

FIRST UNIT COSTS

12,000,000

01/09/74

	DIRECT LABOR GROUPS	DIRECT LABOR COSTS	MATERIAL COSTS	LABOR MATERIAL (%)
BASIC STRUCTURE				
ALIGN				5.193
HORIZONTAL STABILIZED				.575
VERTICAL STABILIZED				5.395
FUSELAGE				1.413
NOSE				.583
LANDING GEAR				
SUBSYSTEMS				
SURFACE CONTROLS				2.452
ENVIRONMENTAL CONTROL SYS				.906
HYDRAULICS/PNEUMATICS				.100
ELECTRICAL				.909
INSTRUMENTS				1.034
AUXILIARY POWER UNIT				.196
ARMAMENT PROVISIONS				.259
ENGINE ASSOCIATED EQUIP				.792
FUEL SYSTEM				
AVIONICS PROVISIONS				.159
ELECTRONICS & EQUIPMENT				.557
SUBSYSTEMS SUBTOTAL				7.791
TOTAL FIRST UNIT COST				22.629

Figure 41. First Unit Costs.

AIRCRAFT VEHICLE AIRFRAME SYSTEM COSTS

RECURRING AIRFRAME MANUFACTURING COSTS

	UNITED STATES	UNITED KINGDOM	FRANCE	GERMANY	ITALY
SUSTAINING ENGINEERING	4.563	23.072	2.475	19.463	
SUSTAINING TOOLING	4.393	67.760	4.433	20.360	
MANUFACTURING					
WING		30.034		119.575	
HORIZONTAL STABILIZER		7.375		11.019	
VERTICAL STABILIZER		77.535		115.435	
FUSELAGE		18.273		27.300	
NACELLE		0.560		15.361	
LANDING GEAR		34.741		64.907	
SURFACE CONTROLS		17.745		22.551	
ENVIRONMENTAL CONTROL SYS		4.842		9.594	
HYDRAULICS/PNEUMATICS		14.360		25.541	
ELECTRICAL		16.334		24.551	
INSTRUMENT					
AUXILIARY POWER UNIT		3.092		5.499	
ARMAMENT PROVISIONS		4.090		7.256	
ENGINE ASSOCIATED EQUIP		12.505		22.342	
FUEL SYSTEM		5.408		10.730	
AVIONICS PROVISION		10.345		19.472	
FURNISHINGS & EQUIP		215.221		587.743	
TOTAL MANUFACTURING					

12,444,540

31/09/75

Figure 42. Recurring Airframe Production Costs.

Appendix B. The derivation of these CERs is discussed in Section 3.2 below. The total CER structure consists of these CER forms expanded by the insertion of the appropriate estimating parameter(s) and cost estimating coefficients. The total structure then corresponds to the items of the computer printout. This correspondence has been defined in Volume II. To illustrate, take the example of Equation (1) (from Appendix B) for Basic Structure Design Engineering, as shown in Figure 43. (This figure is also used to illustrate the discussion of inputs and input organization. Each term of the basic equation represents a series of inputs corresponding to the index numbers for the structural elements estimated.

The correspondence between CERs and cost output is shown in Table 7 (Table 42 from Volume II) for nonrecurring design and development cost. This category accounts for most of the CER forms used. Table 7 is arranged in the same manner as the computer printout, and the referenced equation numbers can be related to outputs. This table provides one additional piece of information: the location in the computer model card deck of the model card containing the estimating equation. Tables giving the above information for the remaining cost categories appear in Section III, Volume II.

$$\begin{array}{c}
 \begin{array}{l} \text{COMPLEXITY FACTOR} \\ \text{HISTORICAL DATA} \end{array} \quad \begin{array}{l} \text{COST/WEIGHT SCALING EXPONENT} \\ \text{HISTORICAL DATA} \end{array} \\
 \swarrow \quad \searrow \\
 DE_i - F_i (EC_i) (WE_i) E_i \\
 \swarrow \quad \searrow \\
 \begin{array}{l} \text{ESTIMATING COEFFICIENT} \\ \text{HISTORICAL DATA} \end{array} \quad \begin{array}{l} \text{SIZE PARAMETER} \\ \text{GROUP WEIGHT STATEMENT} \end{array}
 \end{array} \quad (1)$$

and

DE_i - Design engineering hours for each structural element estimated

i - Index numbers, 1 through 6 for:

- Wing
- Horizontal Stabilizer
- Vertical Stabilizer
- Fuselage
- Nacelles
- Landing Gear

Figure 43. CER Form and Input Definition - Basic Structure Design Engineering.

Table 7. Cost Output, CER Equation, and Model Card Cross Reference -
System Nonrecurring Design and Development Cost.

Hardware Components	Direct Labor Hours	Direct Labor Costs	Engineering Material Costs	Labor and Material Costs
Engineering				
Basic Structure Design Engineering				
Wing	Eq (1) F 701 1			
Horizontal Stabilizer	Eq (1) F 702 1			
Vertical Stabilizer	Eq (1) F 703 1			
Fuselage	Eq (1) F 704 1			
Nacelle	Eq (1) F 705 1			
Landing Gear	Eq (1) F 706 1			
Configuration Design Engineering	Eq (2) F 707 1			
Surface Controls	Eq (3) F 711 1			
Environmental Control System	Eq (3) F 712 1			
Hydraulics/Pneumatics	Eq (3) F 713 1			
Electrical	Eq (3) F 714 1			
Instruments	Eq (3) F 715 1			
Auxiliary Power Unit	Eq (3) F 716 1			
Armament Provisions	Eq (3) F 717 1			
Engine Associated Equipment	Eq (3) F 718 1			
Fuel System	Eq (3) F 719 1			
Avionics Provision	Eq (3) F 720 1			
Furnishings and Equipment	Eq (3) F 721 1			
Total Engineering Labor	Eq (4) R 722 1	Eq (5) F 723 2	Eq (6) F 723 3	Eq (7) F 723 4
Dollar Costs				

Table 7. Cost Output, CER Equation, and Model Card Cross Reference -
System Nonrecurring Design and Development Cost, Contd.

Hardware Components	Wing, Hours	Horizontal Stabilizer Hours	Vertical Stabilizer Hours	Fuselage Hours	Nacelle Hours	Landing Gear Hours	Subsystem Hours	Total Hours	Total Dollars
Tooling									
Basic Tool Manufacturing	Eq (8) F 731 1	Eq (8) F 731 2	Eq (8) F 731 3	Eq (8) F 731 4	Eq (8) F 731 5	Eq (8) F 731 6	Eq (8) F 731 7	F 731 8	
Rate Tool Manufacturing	Eq (9) F 732 1	Eq (9) F 732 2	Eq (9) F 732 3	Eq (9) F 732 4	Eq (9) F 732 5	Eq (9) F 732 6	Eq (9) F 732 7	F 732 8	
Total Tool Manufacturing	F 733 1	F 733 2	F 733 3	F 733 4	F 733 5	F 733 6	F 733 7	F 733 8	F 733 9
Basic Tool Engineering	Eq (10) F 734 1	Eq (10) F 734 2	Eq (10) F 734 3	Eq (10) F 734 4	Eq (10) F 734 5	Eq (10) F 734 6	Eq (10) F 734 7	F 734 8	
Rate Tool Engineering	Eq (11) F 735 1	Eq (11) F 735 2	Eq (11) F 735 3	Eq (11) F 735 4	Eq (11) F 735 5	Eq (11) F 735 6	Eq (11) F 735 7	F 735 8	
Total Tool Engineering	F 736 1	F 736 2	F 736 3	F 736 4	F 736 5	F 736 6	F 736 7	F 736 8	F 736 9
Tool Material									F q (12) F 737 9
Manufacturing Aids								Eq (13) F 738 8	F 738 9
Manufacturing Development								Eq (14) F 739 8	F 739 9
Total Tooling									F 740 9
Manufacturing Support									Eq (15) F 741 9
Quality Control								Eq (16) F 742 8	F 742 9

3.1.3 COMPUTER PROGRAM. The system cost estimating method and the trade study method use the same computer program, sharing different portions of the NAMELIST section and the model card section. The COSTC program deck is common to both methods.

Appendix K of Volume II provides information to describe the system cost estimating computer program module consisting of a listing of input elements, a listing of the program model cards and NAMELIST variable input cards, the SAV matrix printout, a NAMELIST variables dictionary, and a summary of F-card coefficients.

The computer program is operated in different modes (i.e., trade study costing only, system study costing only, dual-mode operation, limited inclusion of hardware elements, and eliminating alternative production quantities) by removing the corresponding model cards from the input deck.

3.1.4 INPUTS AND INPUT ORGANIZATION. Inputs for the system method are organized in the same way as for the trade study method. Inputs are made up of NAMELIST variables and model cards with the latter consisting of estimating coefficients and CERs. Basically, NAMELIST variables relate to the design characteristics of the hardware element estimated and estimating coefficients to the historical data base. CERs are again handled as input data.

The NAMELIST variables dictionary provides for the entry of an input value and thus serves as an input summary table. The summary of F-card coefficients references the location of available back-up data, that is the historical data base.

3.1.5 INPUT SOURCES. Input sources are described in Volume II, Section 3.3, as part of the input description related to the description of CERs. The sources of input data are not formally defined. A group weight statement is required for subsystem weights. Design and program data are obtained from the pre-design activity. The remaining inputs are derived from the historical data base.

3.2 CER DERIVATION

The derivation of the basic CER forms is described in the following sections. Equation numbering is taken from Appendix B.

3.2.1 NONRECURRING DESIGN AND DEVELOPMENT COST. The discussion of CER derivation will be concerned only with primary CERs. Summations, such as equations (4) and (7), and the conversion of hours to dollars, equation (5), are omitted.

In addition, certain of the forms are derived from the trade study method and are not discussed further. These consist of the use of a percentage, factor or ratio

based on manufacturing experience and include:

<u>Title</u>	<u>Equation No.</u>
Engineering Material Costs	(6)
Basic Tool Engineering Hours	(10)
Rate Tool Engineering Hours	(11)
Tool Material Costs	(12)
Manufacturing Aids Costs	(13)
Manufacturing Development Costs	(14)
Quality Control Hours	(16)

The CER for Rate Tool Manufacturing Hours, equation (9), is based on Rand methodology (Reference 8) and is the same as was used in the trade study method. Equation (15), Manufacturing Support Costs, is also based on a Rand concept, Reference 8, with an inflation factor added.

The derivation of the remaining CERs is discussed below. These consist of:

- a. Basic Structure Design Engineering Hours
- b. Configuration Design Engineering Hours
- c. Equipment Design Engineering Hours
- d. Basic Tool Manufacturing Hours

These CERs, except the third one, are also used in the trade study method. Since in the system method concern is for the more broadly defined concept of airframe, a breakout for a complexity factor is provided. (The same results can be achieved in the trade study method by considering the estimating coefficient as consisting of a product: complexity times a baseline estimating coefficient.) In the case of Configuration Design Engineering, this results in a change in the CER form.

Basic Structure Design Engineering Hours

This form and the hardware elements for which it is used were illustrated in Figure 43. The cost data for its derivation is given in Figures I-1 through I-6 in Volume II, Appendix I. Figure 44 reproduces Figure I-1 for purposes of explaining this derivation.

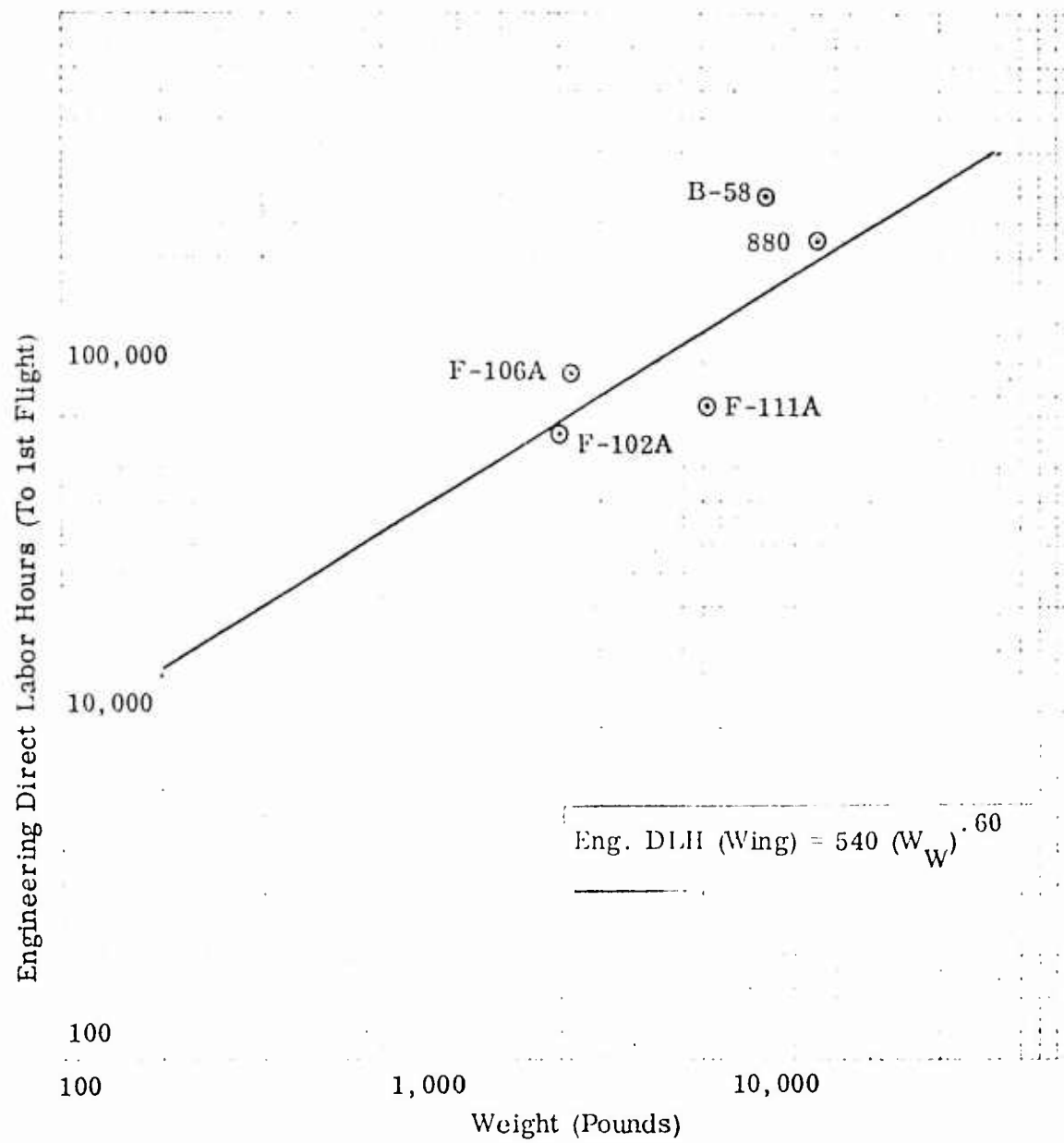


Figure 44. Wing Engineering Cost Estimating Relationship.

This figure shows the form of the CER as used for trade study estimating. The same estimating coefficient and scaling exponent are used in both methods. The system method provides for a complexity factor to be taken at a value other than one in those cases where an analogy to a specific data point is felt to be more accurate than the best fit curve. The same effect can be achieved in the trade study method by means of an F-card change of the estimating coefficient.

With the presently available data base, it appears that for initial engineering labor hours versus weight a scaling factor of 0.60 is a good indicator of the scaling relationship between hours and weight. This scaling factor has been used for each of the elements of the initial engineering task, and the assumption of a consistent trend appears to be verified.

Curve-fitting of the data is accomplished by a freehand graphic method. The estimating coefficient is the value of \overline{EC}_i at $\overline{WE}_i = 1$ lb. The coefficients derived are as follows:

<u>Element</u>	<u>\overline{EC}_i</u>
Wing	540
Horizontal Stabilizer	428
Vertical Stabilizer	400
Fuselage	1200
Nacelle	1200
Landing Gear	560

Configuration Design Engineering Hours

The form of this CER is:

$$CDE = F (EC) (WAMP)^E$$

where

CDE	Configuration design engineering hours
F	Complexity factor
EC	Estimating coefficient
WAMP	AMPR weight of the total basic structure
E	Cost/weight scaling exponent

The data used in the CER derivation is shown in Figure 45. Curve-fitting of the data is again by a freehand graphic method. The estimating coefficient as indicated has a value of 1840.

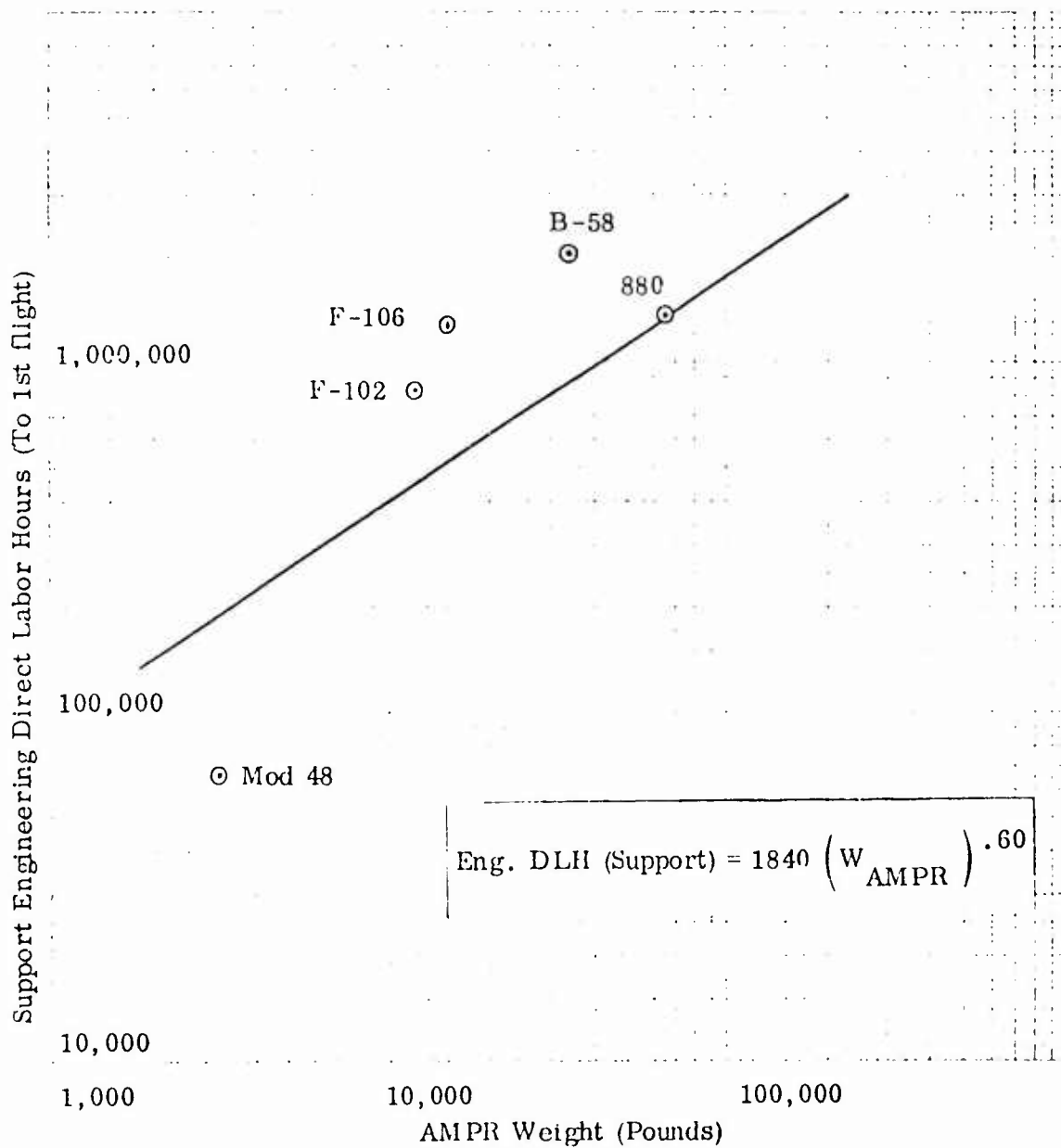


Figure 45. Support Engineering Cost Estimating Relationship.

Equipment Design Engineering Hours

The form of this CER is exactly the same as for basic structure design engineering. The cost data for its derivation is given in Figures L-2 through L-12 in Volume II, Appendix L. Figure 46 reproduces Figure L-3 for purposes of explaining this derivation. The assumption of constant scaling and the method of derivation are the same as above.

Basic Tool Manufacturing Hours

As shown in Figure 39, tool manufacturing labor is estimated in six categories. The data base is given in Figures I-7 through I-11 and I-13. Figure 47 illustrates the data and the derivation. The scaling exponent for tooling is 0.75. The curve-fitting is freehand. The resulting CER form is:

$$BT_i = TF_i (EC_i) (WE_i)^{T_i}$$

where

- BT_i = Basic tool manufacturing hours by hardware element
- TF_i = Complexity factor
- EC_i = Estimating coefficient
- WE_i = Weight of the structural element estimated
- T_i = Cost/weight scaling exponent
- i = Index numbers 1 through 7 for hardware elements

The resulting estimating coefficients are:

<u>Index</u>	<u>Element</u>	<u>EC_i</u>
1	Wing	1300
2	Horizontal stabilizer	750
3	Vertical stabilizer	600
4	Fuselage	1240
5	Nacelles	1240
6	Landing Gear	N/A
7	Other Structure	600

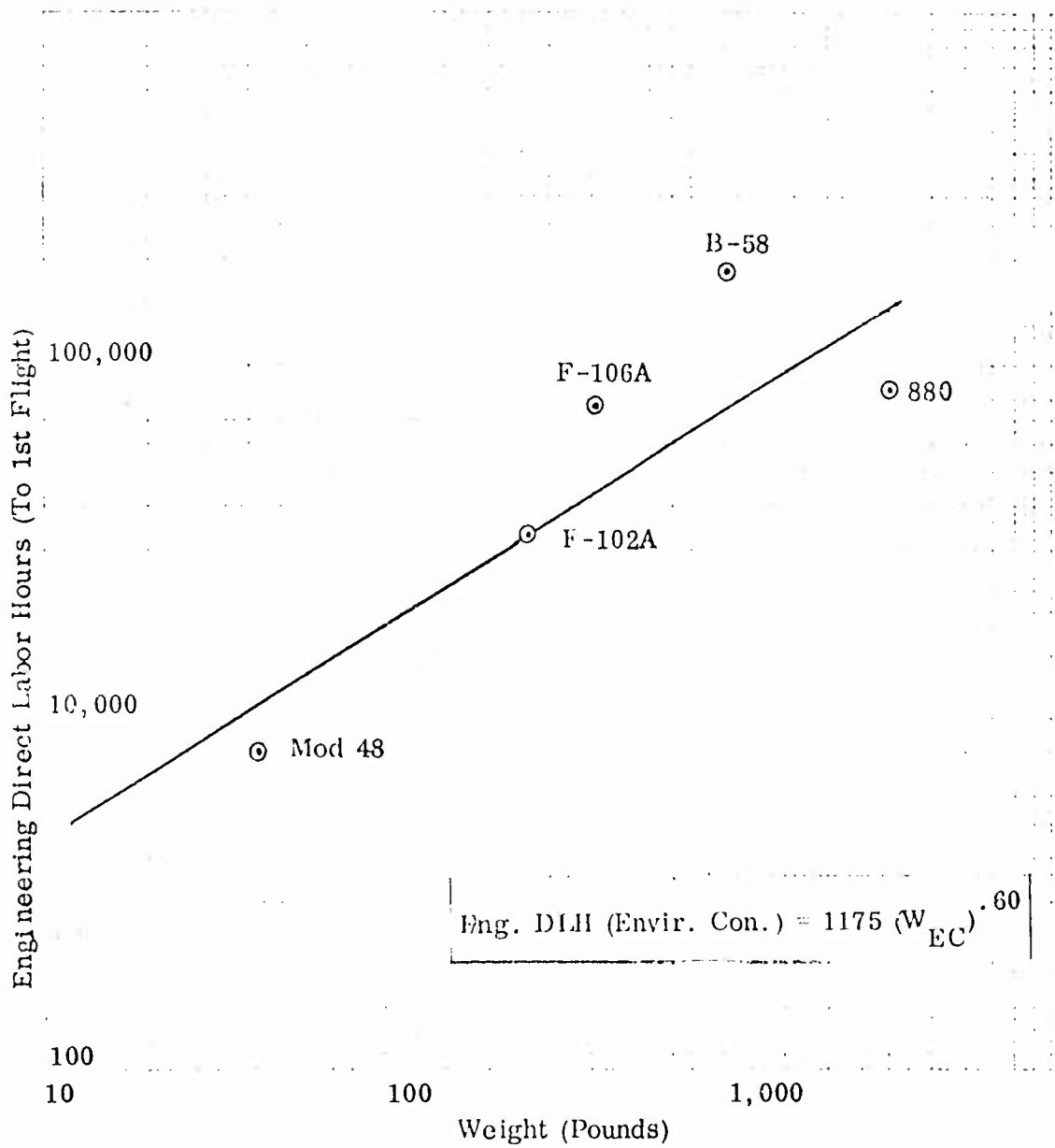


Figure 46. Environmental Control Cost Estimating Relationship.

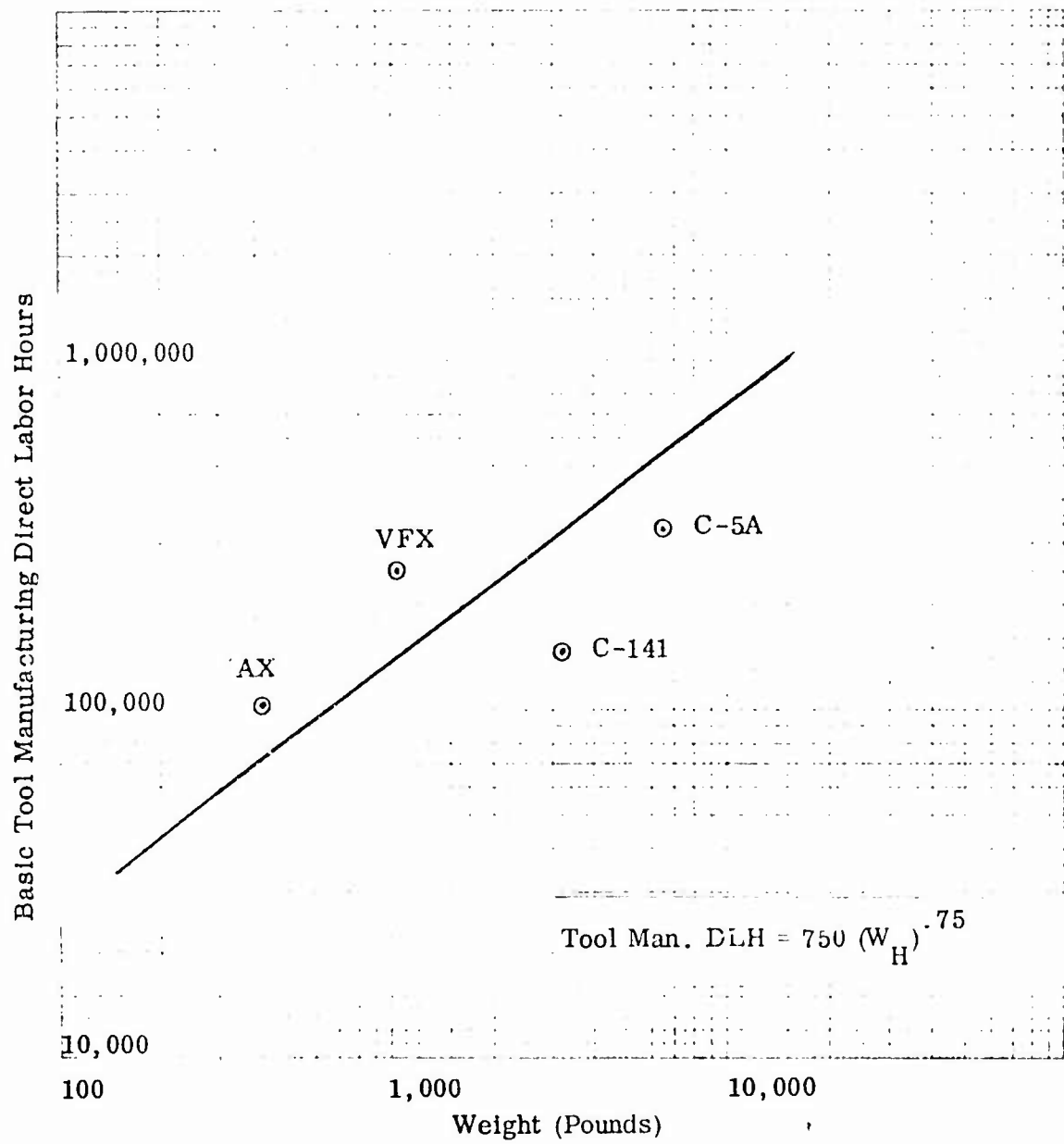


Figure 47. Horizontal Stabilizer Tool Manufacturing Cost Estimating Relationship.

Complexity factors have been developed based on the results of the horizontal stabilizer feasibility study. In the system costing method the estimating coefficients and the complexity factors are used singly whereas in the trade study method these terms are combined as the product TMF. The series of factors was given in Table 6, which is set up for either method.

3.2.2 FIRST UNIT MANUFACTURING COST. Only one CER form is involved in the estimating of first unit manufacturing cost in the system method. It is used for each of the elements of basic structure and mechanical subsystem. It estimates combined labor and material costs. The form is

$$CFU_i = UF_i (EC_i) (WE_i)^{E_i} (INF) + (SAV_i) \quad (17)$$

where

- CFU_i = Labor and material first unit cost of the element estimated.
- UF_i = Complexity factor
- EC_i = Estimating coefficient
- WE_i = Weight of the hardware element being estimated
- E_i = Cost/weight scaling exponent
- INF = Adjustment of 1970 data base to 1974 base
- SAV_i = SAV matrix address for pick-up of trade study method estimate.

This form is the same log-linear relationship previously used. The data base is contained in Figures L-14 through L-30 in Volume II. Figure 48, which reproduces Figure L-17, is used to illustrate.

The assumption of constant cost-weight scaling cannot be made because of the variability introduced by combining labor and material. The data base represented by the above referenced figures was reviewed and fitted by a freehand curve in each case. The resulting set of estimating coefficients and scaling exponents is given in Table 8. These have been entered in the cost model as F-card coefficients.

For all of the subsystems for which equations were generated, a nominal or benchmark set of equation constants is represented with the complexity factor set at one. Excursions are made from this baseline to indicate the effect of changes in a specific design. In some cases, as in Figure 48, multiple curves are assumed based on an apparent stratification of the data.

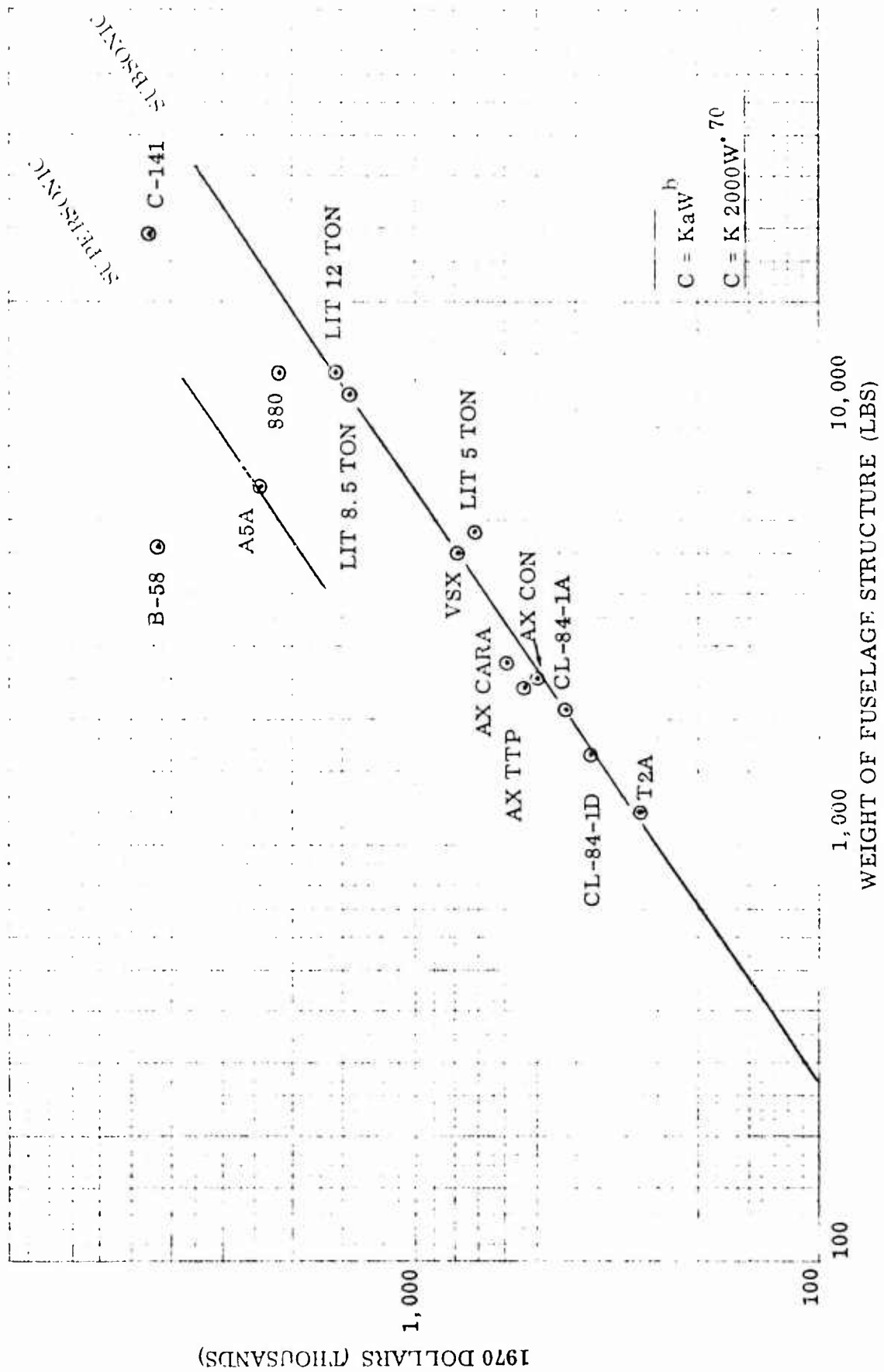


Figure 48. Fuselage First Unit Cost (Labor and Material).

Table 8. First Unit Cost-Estimating Coefficients
and Scaling Exponents.

Hardware Element	Index No.	Estimating Coefficient (EC_i)	Scaling Exponent (E_i)
Wing	1	1680	.70
Empennage	2	2200	.65
Fuselage	4	2000	.70
Nacelles	5	2100	.66
Landing Gear	6	525	.79
Surface Controls	7	1055	.80
Air Conditioning	8	1550	.71
Hydraulics-Pneumatics	9	3200	.70
Electrical Subsystem	10	250	1.00
Instruments and Displays	11	6160	.70
Auxiliary Power	12	1000	.77
Armor Plate	13	640	.70
Engine Associated Equipment	14	640	.86
Fuel System	15	674	.86
Avionics Provisions	16	300	.90
Furnishings and Equipment	17	1570	.75

The adjustment represented by the term INF is as follows:

$$INF = \left[1.273 \cdot (1 + RI)^{(Y-1974)} \right]$$

where

RI = Annual rate of inflation

Y = Dollar reference used for an estimate

The constant, 1.273, represents inflation between 1970 and 1974 based on Reference 12.

The term, SAV_i , in Equation 17 represents the provision for substituting the detailed trade study estimating results in place of estimates made by the first term of the equation. Values are obtained from the SAV matrix at the address where the trade study estimates are entered. For this option, the first term must be zeroed out. The option is used only for basic structure elements.

3.2.3 RECURRING PRODUCTION COSTS. Recurring production costs for the system costing method are handled in a manner similar to that for the Recurring Production Cost Summary for the trade study costing method. The equations used are equations (18) through (22) as shown in Appendix B. Equations (18) and (19) are for Sustaining Engineering for RDT&E and procurement quantities respectively and are based on previously referenced Rand methodology. The same is true of equations (20) and (21) for Sustaining Tooling. Manufacturing recurring costs, projected as dollars based on first unit manufacturing costs, use the Z-card calculation based on TERM 29 (equation 22) as previously described.

3.2.4 OTHER SUPPORTING DATA. Accuracy plots were made in the case of the engineering direct labor CERs (Basic Structure, Configuration Design and Equipment Design Engineering) and the basic tool manufacturing direct labor hours. To provide a visual display of the accuracy with which the methodology estimates historical data points, a plot of estimated engineering hours versus actual engineering hours was made and appears as Figure 49. A similar plot was made for basic tool manufacturing hours and appears as Figure 50. The dotted lines provide a bandwidth for the data points and represent estimates that are 50% below and 50% above actual.

12. Campbell, H. G., Aerospace Price Indexes, Rand, R-568-PR, December 1970.

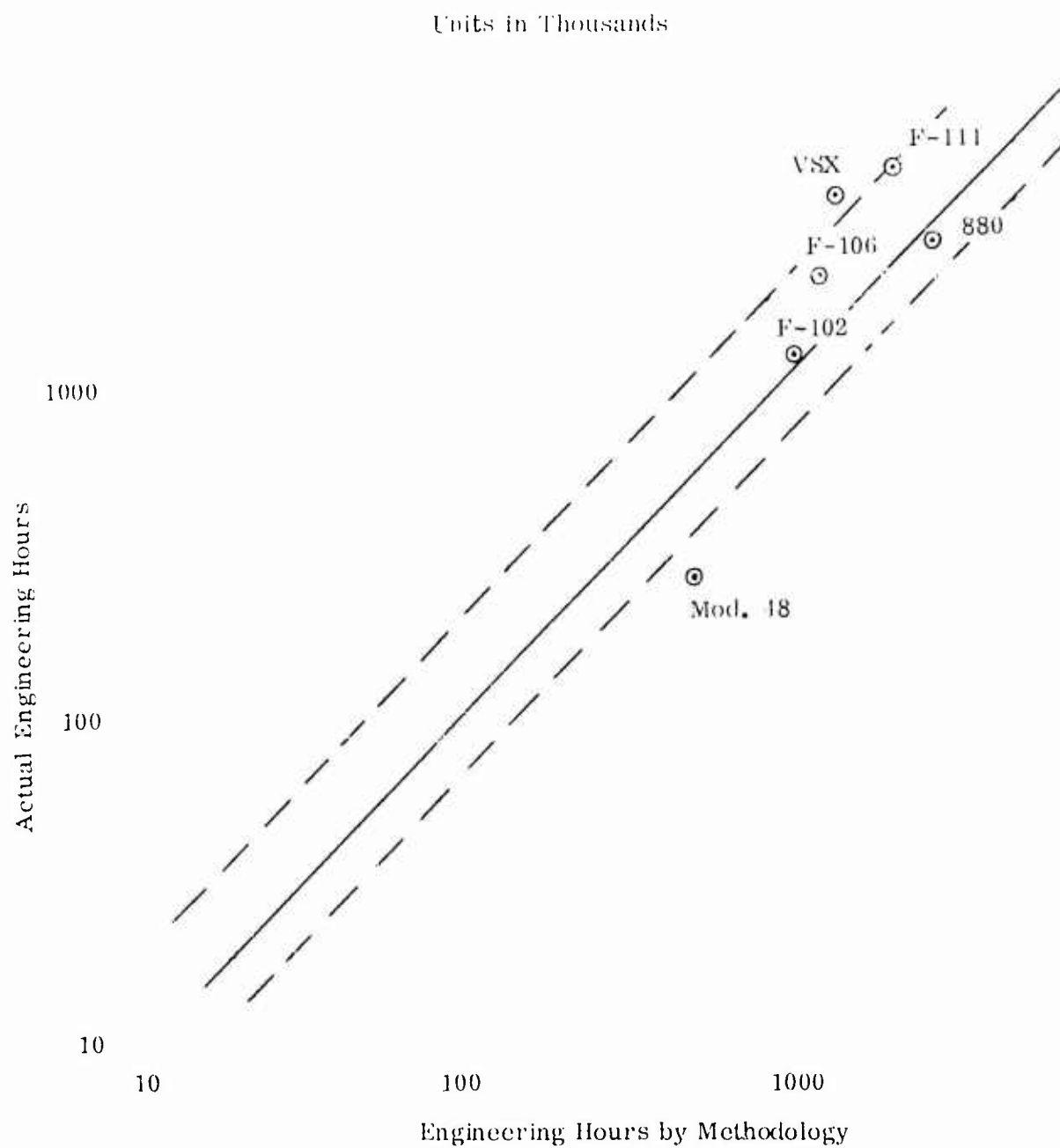


Figure 49. Accuracy Plot for Engineering Hours.

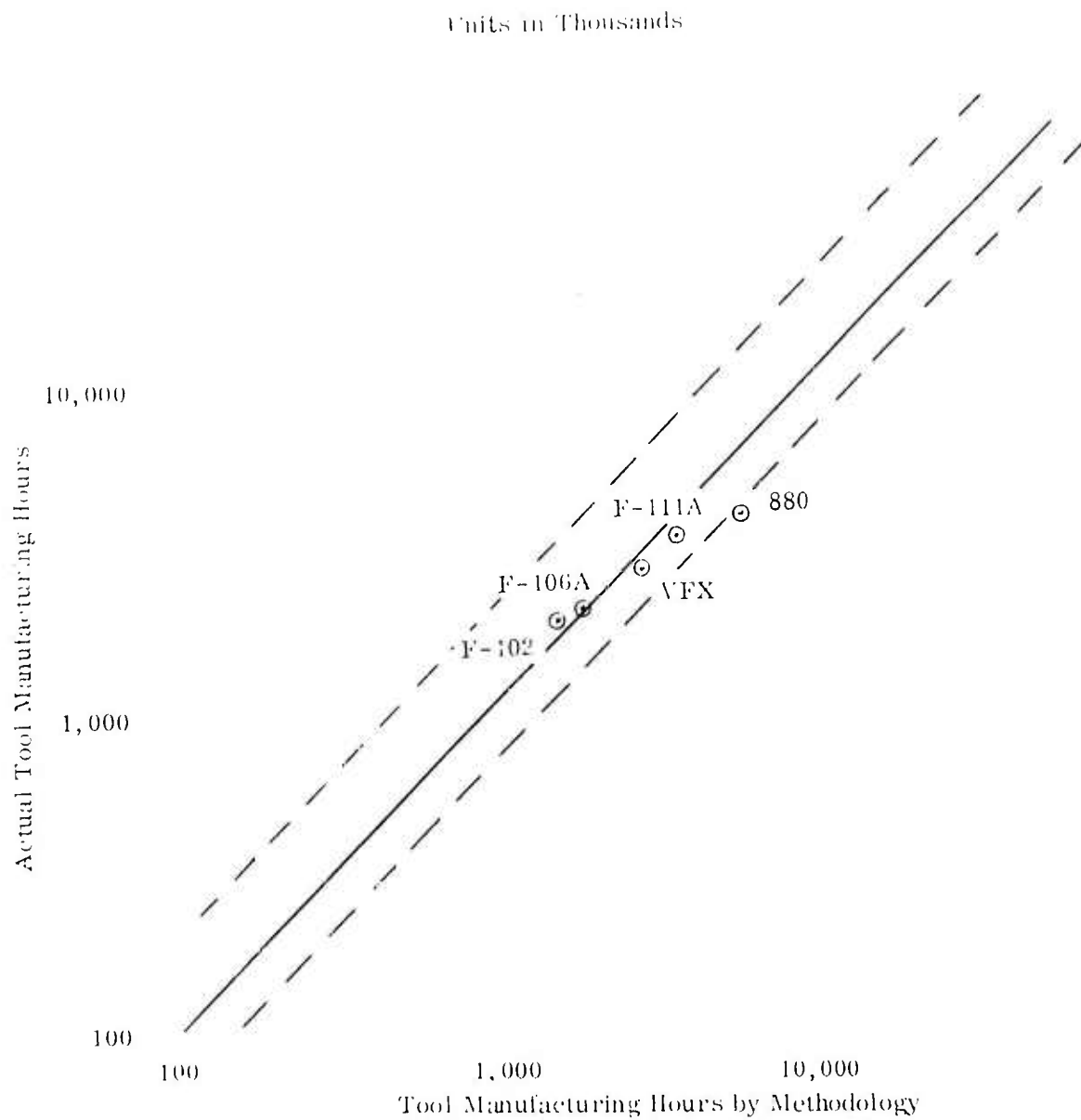


Figure 50. Accuracy Plot for Tool Manufacturing Hours.

SECTION IV

COST MODEL COMPUTER PROGRAM

For reporting purposes the computer programs used in the cost estimating methods are discussed in two parts: the cost model computer program is covered in this section and the so-called supporting programs are discussed in Section V. The latter programs are supporting in the sense that they provide input data to the cost program. This study has been concerned primarily with the development of the cost program and the adoption of existing synthesis programs. An exception has been the development of the computer program for development of aircraft fuselage, landing gear and nacelle weights reported in Section V.

This section is intended only to provide an overview description of the cost model computer program since it is described in operational detail in Section 2.2 of Volume II. In addition, however, some of the reasoning behind the selection of certain features will be described; and in particular, a more complete definition of the COSTC program concept, which is fundamental to the programming, will be provided. Also this section describes the dual mode of operation between the trade study and system costing methods.

The computer program serves to organize the cost estimating task. This estimating process is accomplished in terms of going to the proper sources for the necessary input data, evaluating estimating coefficients in view of additional data acquisition and previous estimating results, setting up the computer program deck, and entering inputs.

4.1 PROGRAM ORGANIZATION

The computer program deck set up is shown in a simplified manner in Figure 51. The principal elements of the program are:

- a. Control cards.
- b. Program deck.
- c. Input cards consisting of:
 - Title card
 - Option card
 - NAMelist input cards
 - Model cards

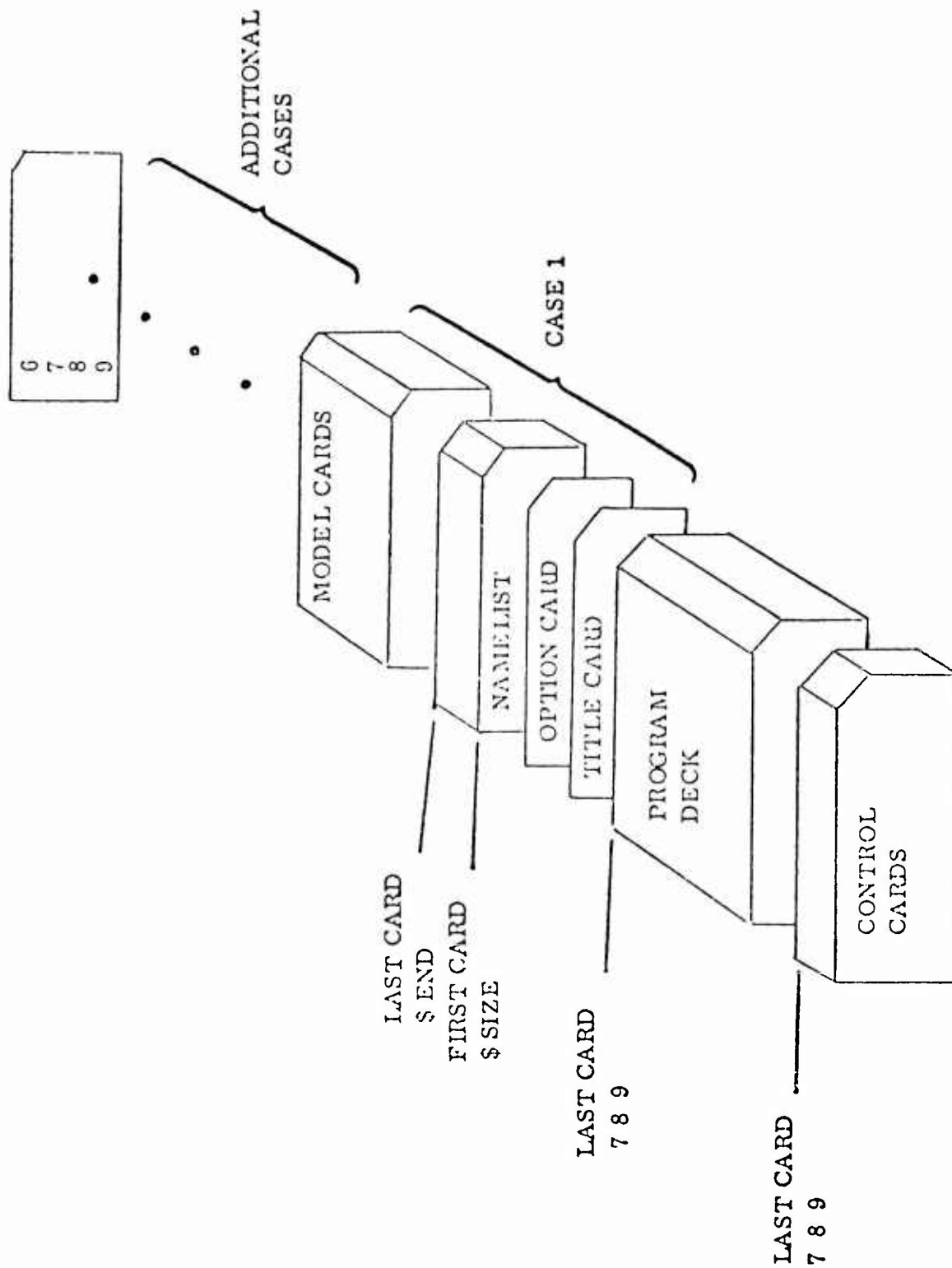


Figure 51. Computer Program Deck Set-Up.

End of record cards are used as shown in Figure 51.

4.1.1 CONTROL CARDS. Control cards are described in Section 2.2.1 of Volume II. Options consist of the source deck with either "RUN" compiler or "FTN" compiler, a binary deck with either compiler, and control cards for updating a routine and executing the updated package with the "RUN" compiler.

4.1.2 PROGRAM DECK. The cost model computer program makes use of a general cost model program, designated as COSTC, taking advantage of certain features of that program. The program source deck list is contained in Appendix C. A general flow diagram of the program is given in Figure 52.

COSTC is a data manager program written in FORTRAN IV for the CDC CYBER 72. The program provides for handling the cost estimating logic (CERs) as a program input whereby they can be changed as an input change (subject to the constraint of making an appropriate NAMELIST and Common Block change). Cost estimating coefficients can also be changed in the same way, that is by a model card change. The program features a SAV matrix that consists of an array by line and column for storing estimating results. This matrix is both addressable for use in subsequent calculations and displayable as a means of recording results and verifying intermediate calculations. An example of the SAV matrix is shown in Appendix C, Volume II as Table C-1. This is a complete matrix (except for the effects of the absence of a horizontal stabilizer) representing the B-58 trade study method test case. The lines and columns are addressable by the model cards. A value "stored" in any element of this matrix may be used as a term, and manipulated by certain types of model cards. The SAV matrix is dimensioned by the driver program, COSTC. The number of rows in the matrix corresponds to the number of lines containing cost values that are to be printed out. In terms of model cards, however, a calculation, i.e., a model card, is required for each element of the matrix. The matrix is limited only by the dimension statement and, in turn, core capacity. The current program is dimensioned for 699 lines and 12 columns. A 13th column is used for summing a given line. The number of columns in the matrix corresponds to the number of columns that can be printed out. The program presets the SAV matrix to zeroes before the execution of a run. Terms are computed and added to a specific location in the matrix addressed by line and column number by the operative model cards. The function of the SAV matrix leads to a discussion of model cards. This is included in the discussion of input cards below.

The trade study method and the system study method use identical control cards and program deck. Identification of the method comes about in the Input Cards.

4.1.3 INPUT CARDS. A printout of a complete set of input cards is shown in Volume II, Appendix A and Appendix K, for the trade study and system costing methods, respectively. The title card is omitted because it appeared as a blank

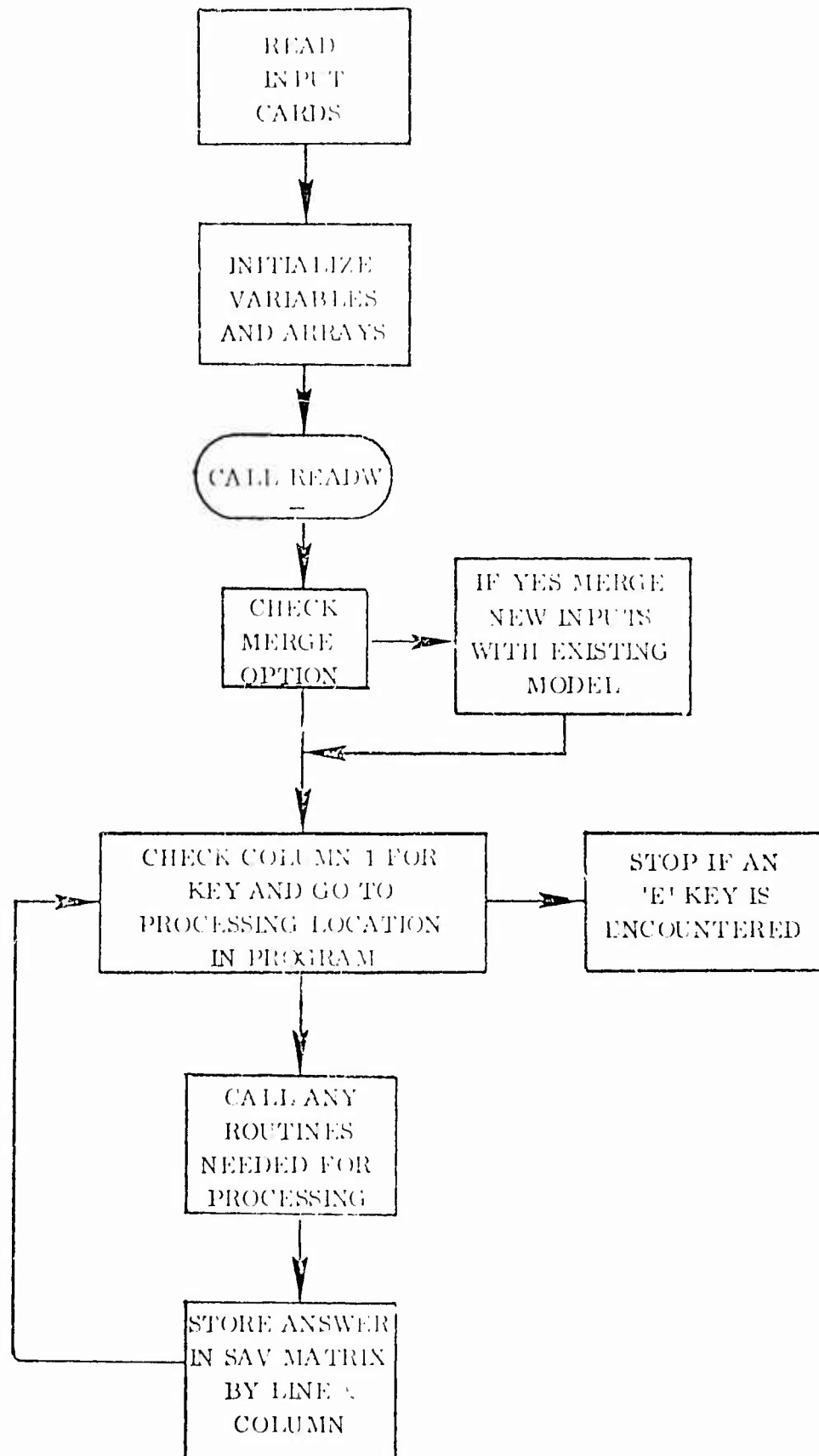


Figure 52. COSTC General Flow Diagram.

card in the test case. The Title card uses 80 columns of alphanumeric data to be printed as the main title.

The Option card has as its purpose control of the initializing of previously used input variables, control of the process of merging model cards with previous cost model information, specification of the maximum number of variables to be used by an element of the model, naming of the six elements, in sequence, that the model is capable of handling. Operational information on the use of the Option card is given in Volume II, Section 2.2.3.

NAMelist input cards record the input variables. The NAMelist identifiers are SIZE, CURVE, and SUMMARY, which is part of the system costing method. One set of variables in a NAMelist card corresponds to an element of the model. As many blocks are read as are specified by the number of elements punched in the option card, and the inclusion or exclusion of an element is controlled by the option card. Sets of variables must then be furnished to correspond.

The first case should contain all the variables that are used by the model. For subsequent cases, only the variables that are to be changed are input. Variables are stored in a single dimensional array called PL. They are stored by elements and are printed out by element for each case run. A sample input element printout is shown in Appendix B, Volume II.

The model cards consist of a series of different type cards that carry the costing logic. These cards perform different functions, and column one of each card is used as a "key" to determine the specific function of that card. The functions of the various types of model cards are described in Volume II, Appendix A, including the rules applicable to the use of each type of card. The cards are discussed in the order in which they appear in the printout in Appendix A, except that all of the input oriented cards are grouped together and discussed first. The complete list of card types in the order in which they appear in the model deck, is B-card; 1-card; 2-card; 3-card; F-card; blank-card; C-card; N-card; T-card; D-card; R-card; P-card; Z-card; L-card; and E-card. The input oriented cards are: F-card; R-card; Z-card.

To illustrate the operation of the matrix and the function of the model cards, excerpts from the SAV matrix from Volume II and the model card input data listing are shown as Figures 53 and 54, respectively. The enclosed area in Figure 53 corresponds to the subset of model cards listed in Figure 54. To further illustrate the relationship, the first entry in Figure 54 is as follows.

```
F 12 6 W5 WNG . . . 77 RMC5 WNG SF5 WNG W6 WNG . . . 77 RMC6 WNG
      SF6 WNG
```


F 12	6	NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10
F 12	9	NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10 (NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10)
F 13	3	NO HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL
F 13	6	NO HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL
F 13	9	NO HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL (NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10)
F 14	3	NO VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL
F 14	6	NO VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL
F 14	9	NO VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL (NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10)
F 15	1	NO W10**77**C0 W10**77**C0 W10**77**C0 W10**77**C0 W10**77**C0 W10
F 15	4	NO HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL**77**C0 HIL
F 15	7	NO VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL**77**C0 VIL (NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10)
F 15	8	2.0*((C0*HIL + HIL*HIL + SF0*HIL + SF0*HIL)**.95)
F 15	9	2.0*((C0*HIL + HIL*HIL + SF0*HIL + SF0*HIL)**.95)
F 15	10	2.0*((C0*HIL + HIL*HIL + SF0*HIL + SF0*HIL)**.95) (NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10)
F 16	1	((A0*HIL**77**C0)+(7.0)*.20 + (15.0)) * 2.0 NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10
F 16	2	((C0*HIL + HIL*HIL) * 1.216 * (6.1) * 2.0 (SF0*HIL**77**C0)*1.04*2.0 (PANEL FIT + TRIM)
F 16	3	((15.1) * 1.238 * 2.0 PART A *HIL*2.0 (ASSY CLAMP + LAYOUT)
F 16	4	((15.1) * .957 * (6.1) * 2.0 PART A *HIL*1.04*2.0 (HOLE DRILLING)
F 16	5	((15.1) * .216 * (6.1) * FF1 W10 * 2.0 PART A *HIL*1.04*FF1*2.0 (FINISH OPERATIONS)
F 16	6	((15.1) * .970 * (6.1) * FF2 W10 * 2.0 PART A *HIL*1.04*FF2*2.0 (FASTENER INSTALLATION)
F 16	7	((15.1)*(15.1)*(15.1)+(15.1)+(15.1)+(15.1)) * .08 * FF1 W10 TOTAL ASSY LABOR HOURS *AFF1*FF1 (NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10)
F 17	1	((15.1)*(15.1)+(7.0)*.20 + (15.10) NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10
F 17	2	((C0*HIL + HIL*HIL) * 1.216 * (6.4) * 2.0 (SF0*HIL**77**C0)*1.04*2.0 (PANEL FIT + TRIM)
F 17	3	((15.4) * 1.238 * 2.0 PART A *HIL*2.0 (ASSY CLAMP + LAYOUT)
F 17	4	((15.4) * .957 * (6.4) * 2.0 PART A *HIL*1.04*2.0 (HOLE DRILLING)
F 17	5	((15.4) * .216 * (6.4) * FF1 HIL * 2.0 PART A *HIL*1.04*FF1*2.0 (FINISH OPERATIONS)
F 17	6	((15.4) * .970 * (6.4) * FF2 HIL * 2.0 PART A *HIL*1.04*FF2*2.0 (FASTENER INSTALLATION)
F 17	7	((17.1)*(17.1)+(17.1)+(17.1)+(17.1)+(17.1)) * .34 * FF1 HIL TOTAL ASSY LABOR HOURS *AFF1*FF1 (NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10)
F 18	1	((15.7)*(15.7)+(7.0)*.20 + (15.10) NO APL**77**MCS 11**F0 W10*W0 W0**77**C0 A.G*SF0 W10
F 18	2	((C0*HIL + HIL*HIL) * 1.216 * (6.7) (SF0*HIL**77**C0)*1.04 (PANEL FIT + TRIM)
F 18	3	((15.7) * 1.238 PART A *HIL (ASSY CLAMP + LAYOUT)
F 18	4	((15.7) * .957 * (6.7) PART A *HIL*1.04 (HOLE DRILLING)
F 18	5	((15.7) * .216 * (6.7) * FF1 VIL PART A *HIL*1.04*FF1 (FINISH OPERATIONS)
F 18	6	((15.7) * .970 * (6.7) * FF2 VIL

Figure 54. Excerpt from Model Card Listing.

```

C          E-604 TEST CASE
C          USE OF DECIMAL FRACILES UNITS IN MILLIONS
C
C          FIRST UNIT COST
C
C          WING
N 9
T
C          STRUCTURAL BOX
F 31 1 (5,1) / (5,3) * 51.0 * (5,3)**.67
           HF1 E1
F 31 2 (9,2) / (5,3) * 16.5 * (5,3)**.67
           HF4 E4
F 31 6 WC1 WNG**+.77 * RMC1 WNG * SF1 WNG + (12,3)
D          NIPS
F 32 1 (6,1) / (6,3) * 52.0 * (6,3)**.67
           HF2 E2
F 32 2 (10,2) / (6,3) * 19.0 * (6,3)**.67
           HF5 E5
F 32 6 WC4 WNG**+.77 * RMC4 WNG * SF4 WNG + (12,6)
D          SPARS
F 33 1 (7,1) / (7,3) * 11.0 * (7,3)**.67
           HF3 E3
F 33 2 (11,2) / (7,3) * 7.2 * (7,3)**.67
           HF6 E6
F 33 6 WC7 WNG**+.77 * RMC7 WNG * SF7 WNG + (12,9)
D          COVERS
C
F 34 3 (10,1)+(10,2)+(10,3)+(10,4)+(10,5)+(10,6)
F 34 4 (10,7) * 1.0
D          ASSEMBLY
R 35 1 6 3 4 31 1
D          STRUCTURAL BOX SUB-TOTALS
F 36 1 (35,1) * RM WNG
F 36 2 (35,2) * RM WNG
F 36 3 (35,3) * RM WNG
D          LABOR COSTS ($)
C
C          SUBCOMPONENT STRUCTURE
F 38 1 CC1 WNG * 55.0 * WD1 WNG**+.67
           WC1 E7
F 38 2 CC1 WNG * 46.0 * WD1 WNG**+.67
           WF1 F1
F 38 6 WC1 WNG**+.77 * RMC10 WNG * SF10 WNG
D          LEADING EDGE
F 39 1 CC2 WNG * 29.0 * WD2 WNG**+.67
           WC2 E8
F 39 2 CC2 WNG * 23.0 * WD2 WNG**+.67
           WF2 F2
F 39 6 WC2 WNG**+.77 * RMC11 WNG * SF11 WNG
D          TRAILING EDGE
F 40 1 CC3 WNG * 35. * WD3 WNG**+.67
F 40 2 CC3 WNG * 47. * WD3 WNG**+.67
F 40 6 WC3 WNG**+.77 * RMC12 WNG * SF12 WNG
D          ALLERONS
F 41 1 CC4 WNG * 36. * WD4 WNG**+.67
F 41 2 CC4 WNG * 34. * WD4 WNG**+.67
F 41 6 WC4 WNG**+.77 * RMC13 WNG * SF13 WNG
D          FAIRINGS

```

Figure 54. Excerpt From Model Card Listing (Continued).

This is an "F" card as noted by the F in the first column. The SAV matrix element in which the results of the calculation are entered is line 12 and column 6. The entry there, as shown in Figure 53, is 1.85E + 04, or 18500. From the equation it can be determined that this is in dollars. This is an intermediate calculation and does not appear in the computer printout. The equation itself is defined as follows:

W5 WNG	=	Weight of 2nd kind of spar ¹
W6 WNG	=	Weight of 3rd kind of spar
.77	=	Empirically derived scaling exponent
RMC5 WNG	=	Raw material cost for 2nd type of spar
RMC6 WNG	=	Raw material cost for 3rd type of spar
SF5 WNG	=	Scrapage factor for 2nd type of spar
SF6 WNG	=	Scrapage factor for 3rd type of spar

The designation WNG refers to the wing. This calculation for each of the other basic structure elements is exactly the same with the substitution of estimating coefficients and NAMELIST variables appropriate to the element to be estimated. The first type of spar (not shown above) is estimated by F-card, F 32 6, which in addition, picks up the total of F 12 6 to provide the cost printout appearing in Figure 9 under Structural Box, Spars, Material Cost, in the amount of \$29,503. The corresponding SAV matrix entry is indicated in Figure 53.

The F-card entry for F 32 6 is as follows:

$$F\ 32\ 6\ W4\ WNG = (.77 + RMC4\ WNG + SF4\ WNG) \cdot (12,6)$$

where

W4 WNG	=	Weight of 1st type of spar
RMC4 WNG	=	Raw material cost for 1st type of spar

-
1. That the hardware element is a spar is determined from the number 5. Primary structure hardware elements are numbered as follows:

W1	Weight of 1st type of rib	W5	Weight of 2nd type of spar
W2	Weight of 2nd type of rib	W6	Weight of 3rd type of spar
W3	Weight of 3rd type of rib	W7	Weight of 1st type of cover
W4	Weight of 1st type of spar	W8	Weight of 2nd type of cover
		W9	Weight of 3rd type of cover

Provision is thus made for handling three different type of ribs, spars and covers.

ST1 WNG	Scrappage factor for 1st type of spar
(12, 6)	Answer recorded in the SAV matrix element at line 12, column 6.

The above also illustrates the capability for simultaneously handling up to three types of material or construction. The various estimating coefficients used throughout the model, such as the exponent, 0.77, are subject to change, which can be accomplished simply by an appropriate model card change.

4.1.4 INPUT CATEGORIZATION. The basic categorization of inputs in terms of input cards, per se, and changes to coefficients contained on the model cards is shown in Figure 55. NAMELIST variables consist primarily of data that corresponds to the physical characteristics of the hardware being estimated. Model card coefficients consist of values derived from historical data, experimental studies, and occasionally, judgment factors. As such they are subject to review and change over time. Another contractor using the method would probably need to adjust the coefficients to his own data base.

4.1.5 TRADE STUDY AND SYSTEM COSTING MODULARIZATION. As stated above the control cards and the program deck are common to both estimating methods. Input card segregation controls the choice of method. A comparison of the first page of each of the input data deck listings contained in Volume II, Appendix A and K, will show the respective use of NAMELIST input cards. In the case of model cards the segregation is as follows:

- a. Trade study method: Lines 1 through 658
- b. System study method: Lines 701 through 800.

The intervening block is reserved for possible expansion of the trade study method or the future addition of features.

4.2 DUAL MODE OPERATION

The concept of using the two methods in conjunction is shown in Figure 56. This is accomplished through the model cards by starting with the system costing method and substituting elements of the trade study method. This is illustrated in Figure 57 and 58, using the wing as an example. Only First Unit Manufacturing Cost is directly affected, but as it changes, the change is reflected in the projections for Recurring Production Cost.

Figure 57 is the relevant section of system method model card listing. In the case of the wing, zeroing out the first term of the entry,

NAMELIST INPUTS:

- DIMENSIONAL DATA
- WEIGHTS DATA
- COMPLEXITY FACTORS
- PROGRAM DATA
- MATERIAL COST FACTORS
- LABOR RATES
- LEARNING CURVES

MODEL CARD COEFFICIENTS

- BASELINE COSTING FACTORS
- SCALING EXPONENTS
- ENGINEERING FACTORS
- TOOLING FACTORS
- FIRST UNIT COSTS (COMPUTED)



NAMELIST:

- SIZE
- CURVE
- SUMMARY



MODEL CARDS:

- F -
- Z -
- OTHER -

Figure 55. Input Categorization.

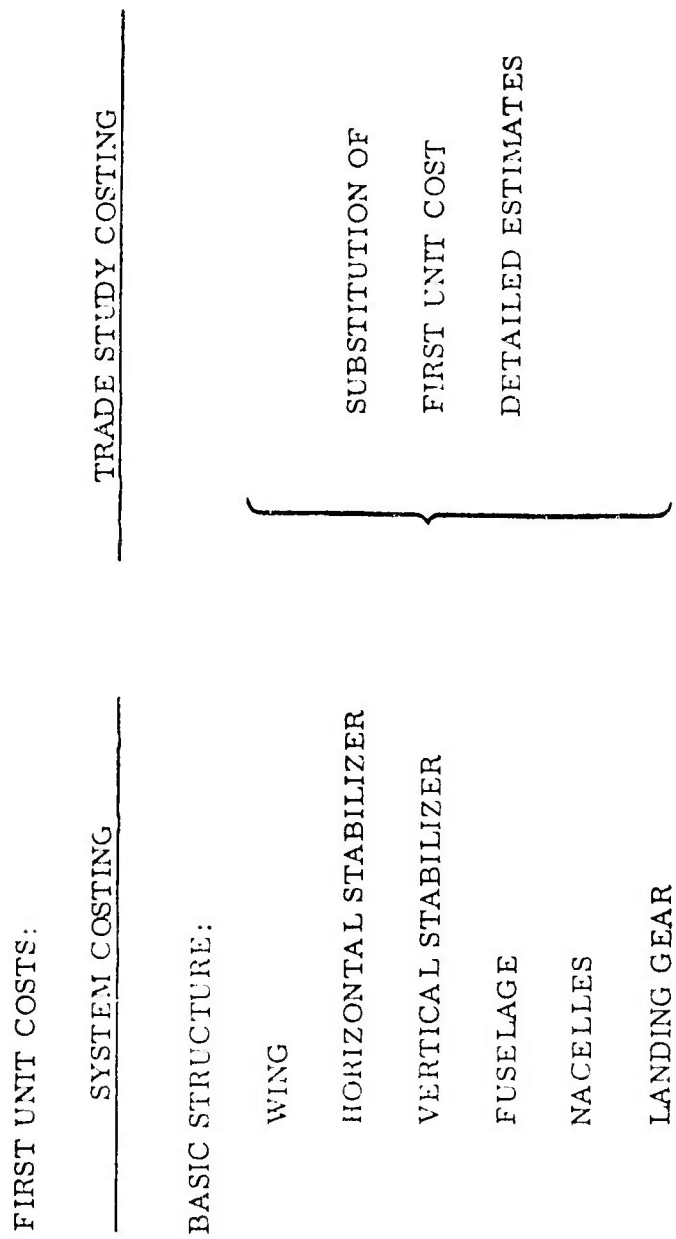


Figure 56. Dual Mode Operation.

Figure 57. Model Card Listing - Dual Mode Provision.

$$F 751 = UF1 \cdot WNG + 1680.0 + WW \cdot WNG + .70 + (740,11) + (61,9)$$

and substituting the value from SAV matrix element (61,9) accomplishes the modular interaction. Reference to Figure 58 shows the preliminary calculations for the entry (61,9). Each of the subsequent calculations referenced in sequence are required for the final total. If a trade study cost estimate had not previously been made, and presumably this would be the usual case, the supporting input data would be required. The entire sequence can be traced by reference to Appendix A of Volume II.

SECTION V

DESIGN SYNTHESIS AND WEIGHT ANALYSIS SUPPORTING PROGRAMS

The trade study cost estimating method relies on the output of a defined set of design synthesis programs to operate in an iterative mode for preliminary design trade studies. Although it can be used for a single point design estimate using manually derived inputs, the costing concept as it is structured requires an interface with computerized design synthesis programs for design inputs. This is not true of the system costing method, which is structured to require more routine types of input. The required trade study supporting synthesis programs are discussed in this section.

Input development was illustrated in Figure 20, showing in general the interaction of the supporting programs and their output. These programs are:

- a. The Multistation Structural Synthesis Program.
- b. Tip, Leading Edge and Trailing Edge Analysis.
- c. Computer Program for Development of Aircraft Fuselage, Landing Gear and Nacelle Weights.

The interface between the costing program and the preliminary design activity is largely defined by the input/output relationship between these programs and the cost model. The preliminary design activity comprises, of course, a considerably greater area, including the possibility of other computerized design synthesis programs to provide inputs to the supporting programs described. Such areas and their possible integration have not been considered in this study.

The elements of the existing estimating method have been designed to operate in a modular mode, as opposed to being hard-wired or having an integrated input/output interface, for two reasons: (1) Each of the elements is in a state of development and changes in input/output are to be expected and (2) It was desired to have the capability of operating the costing program independent of the structural synthesis program, limited, of course, to those cases where the necessary input data could be provided manually.

Coordination of the operation of the supporting programs in the process of input development is accomplished by means of a set of instructions consisting of input and output worksheets. This is completely described in Volume II. The sequence of operations for the programs involved in analyzing aerodynamic surfaces is shown in Figure 40 of that volume. The sequence of operations for fuselage, nacelles and landing gear is shown in Figure 41. An illustrative set of worksheets is included and

discussed in Appendix J of Volume II.

In addition to the discussion of the supporting programs, results of a study to investigate finite element structural synthesis methodology as a possible additional or alternative supporting program are also described in this section.

5.1 MULTISTATION STRUCTURAL SYNTHESIS PROGRAM

A multi station synthesis approach is used for aerodynamic surfaces, including wings other than deltas, and for simple fuselages. The approach adopted for this estimating program is called the Automated Program for Aerospace-Vehicle Synthesis (APAS). As shown in Figure 20, APAS, given the required inputs, provides the following:

- a. Dimensional data
- b. Structural sizing and theoretical weights for aerodynamic surfaces primary structure, which when analyzed against weight correlation factors provides weight estimates.
- c. Structural sizing and theoretical data for input to the program for development of aircraft fuselage, landing gear and nacelle weights (F-N-L).

The APAS program has been developed primarily with Independent Research and Development Funds. It has been an integral part of the estimating method since the feasibility study. It was used and demonstrated as part of the aerodynamic surfaces estimating module and has been described in Reference 2, Volume II.

The multistation structural synthesis program was modified to add a weight estimating capability for primary structure for use in the aerodynamic surfaces module. Weight correlation factors are used in the methodology as illustrated in Figure 59. References 13 and 14 provide a complete description of the program development.

Structural synthesis is a way of satisfying the design problem of defining a piece of structure that fulfills requirements of strength, geometry and other criteria. It

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13. Larry M. Peterson, "Multiple Station Structural Synthesis for Lifting Surfaces," General Dynamics Report, GDCA-ERR-1732, November, 1972.
 14. Gary S. Kruse and Larry M. Peterson, "Automated Structural Sizing Techniques for Aircraft and Aerospace Vehicle Structures," General Dynamics Report, GDCA-ERR-1748, December, 1972.

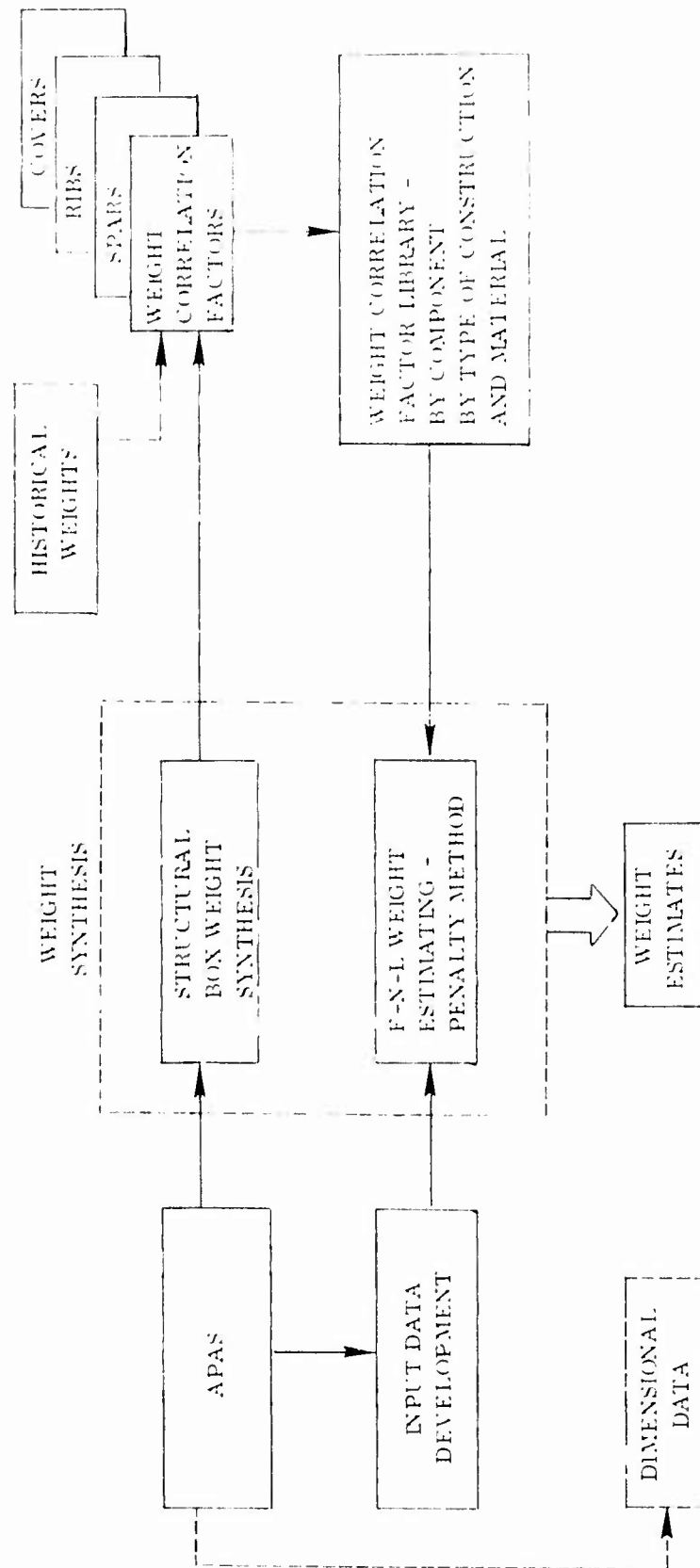


Figure 59. Cost Estimating Procedures Design Synthesis Interface.

combines material properties, structural analysis techniques, and loading environments to produce a consistent design. The interface between the cost estimating procedures and the design synthesis is depicted in Figure 59. The structural synthesis replaces hand calculations with an automated series of logical steps. It offers advantages in solution speed and accuracy. Mathematical optimization techniques have been incorporated that are untractable by hand calculations.

A brief summary of the program follows. Design synthesis proceeds systematically from root to tip, in discrete steps, usually at rib locations, in a two phase system. In the first phase of the synthesis process, a set of initial member size estimates is analyzed. Margins of safety are computed. Thickness variables of all elements are adjusted by iterative steps until each element has a zero margin of safety or until a minimum gage constraint is encountered. The second phase seeks to maximize margins of safety by refinement of element geometry while holding structural weight constant. When this has been accomplished the design is recycled through phase one to further refine structural weight. This logic is repeated until satisfactory convergence is obtained.

The fact that margin of safety maximization rather than weight minimization is used in the second phase permits use of unconstrained function optimization methods. Major advantages of this approach are: the member sizes can be constrained to lay within practical limits of material sizes and manufacturing capability; multiple failure modes may be taken into consideration for each structural element; positive margins of safety are always maintained so that a satisfactory design - from the strength point of view if not the weight - is available at the completion of each iteration.

An accurate representation of geometry is permitted by defining discrete nodes on the contour of the surface. The calculation of internal loads distribution is improved over previous programs by incorporation of methodology for analysis of a multi-cell box beam. Complex bending, shear and torsional loads may be applied. Axial loads and shear flows are computed for each node point and panel. Beams are limited to a maximum of four cells. The discrete nodes used in defining the contours are also used as elemental centers of mass. A spinoff of this modeling scheme is the ability to represent surfaces using the dated constructional mode of concentrating the bending material in the spar caps.

The nature of the element determines the failure modes that receive investigation. Typically gross stress, buckling and crippling checks are appropriate. Dimensional constraints may also be viewed as failure modes and geometric margins of safety may be computer.

Flight safety criteria other than static strength are also considered. Aero-elastic phenomena may be investigated to determine flutter and divergence speeds. A review of structural integrity for a given service loading environment can be

accomplished by safe life, fail safe or fatigue analysis. These routines and checks are informative in nature and do not initiate a redesign cycle, but serve as flags that a design decision is required. Decisions such as material change, criteria revision, mission revision, etc., are typically considered at this point in design evolution.

A flow diagram of APAS is included as Figure 60. Although understanding the program to this depth probably requires recourse to the references. This program represents the adaptation of a general multi station synthesis program, Reference 11, to the particular requirements of aerodynamic surfaces. A program listing has been made available, separately.

5.2 TIP, LEADING AND TRAILING EDGE ANALYSIS

In Figure 20, this program is referred to as "Aerodynamic Surfaces Secondary Structure Synthesis and Weight Analysis." It is a computer program for estimating the geometry, weights, part definition and primary cost drivers for aerodynamic surfaces leading edge, trailing edge and tip components. The aerodynamic surface structural box is not included as part of the program. However, the output is designed to complement structural box analysis to provide complete coverage of the aerodynamic surfaces. APAS uses beam-analysis methods not applicable to secondary structure, hence the resort to other methods of analysis.

The secondary structure synthesis program has been described in Reference 2, Volume II. A very brief description is given in this report dealing with the two processes of the method: the geometry and analysis of the leading edge, trailing edge and tip components and component part definition.

Tip, Leading and Trailing Edge Analysis

The leading edge, trailing edge, and tip synthesis modules provide the capability to analyze the aerodynamic surface structural components that are not considered as part of the structural box. The leading edge is defined as being forward of the front spar and includes the fixed portion of the leading edge and the leading edge high lift devices (slats). The trailing edge is defined as being aft of the rear spar and includes the fixed trailing edge, foreflaps, flaps, ailerons, rudder, elevator, and spoilers. The tip is defined as that structure outboard of the structural box tip closing rib.

The synthesis includes a definition of part geometry and a detailed stress analysis that determines gages, accounts for material types, and sets minimum gage constraints. The geometry routines provide dimensional input to the stress analysis routines. The geometry and stress routines output includes part size and weight, as well as parameters for the part definition. A generalized flow of the leading

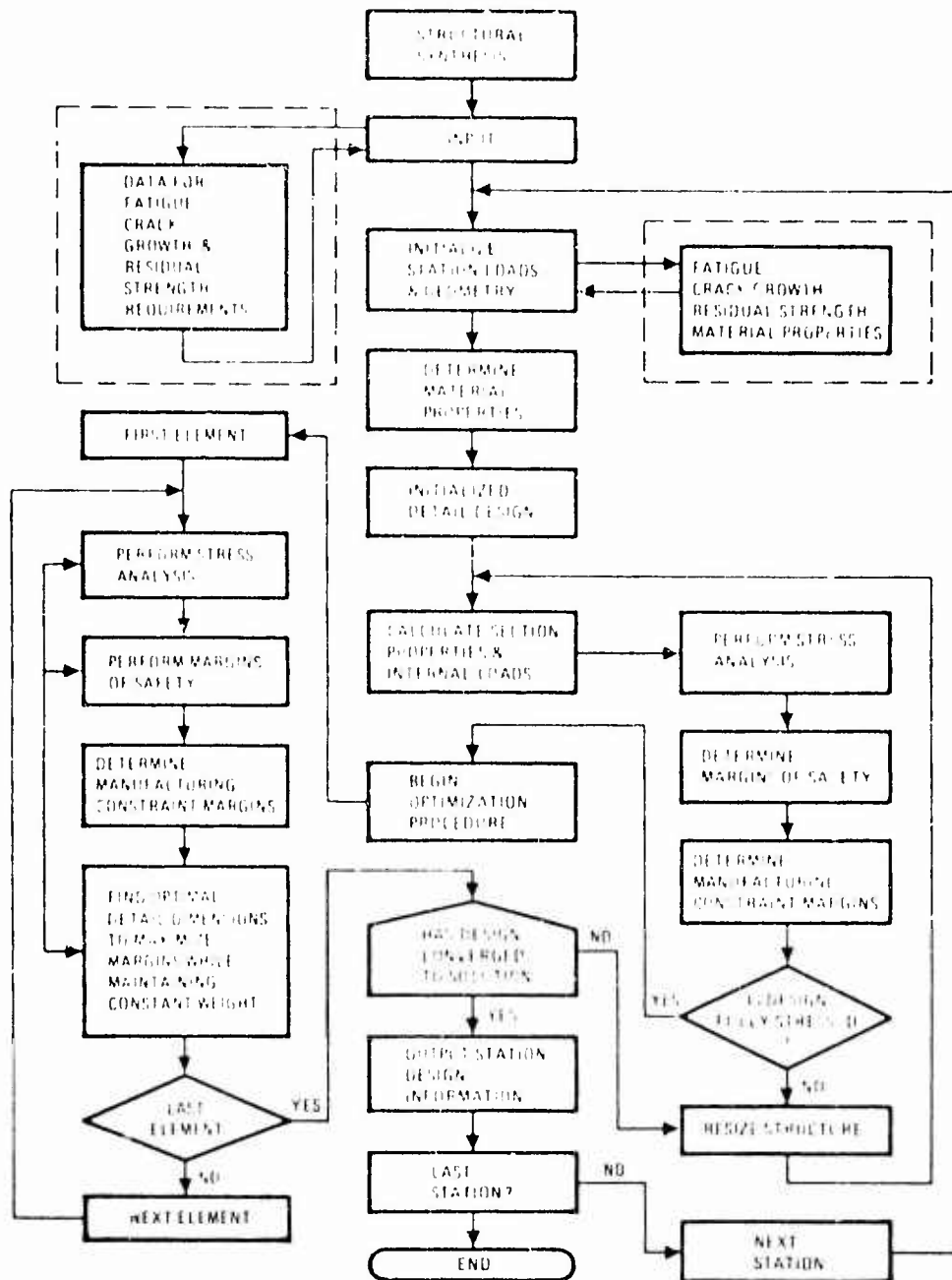


Figure 60. APAS Flow Diagram.

edge, trailing edge, and tip subprogram is shown in Figure 61.

The analysis utilizes eight geometry routines, three stress analysis routines, six supporting routines, and two calling routines. The geometry routines are for flaps, aileron, rudder, elevator, slat location, slats, fixed leading edge, and spoilers.

The stress analysis routines include foreflap, spoiler, and one which analyzes the flaps, ailerons, slats, rudder, and elevator. The supporting routines derive dimensions, material properties, and general analysis. A discussion of these routines was included in the Interim Report.

Tip, Leading and Trailing Edge Part Definition

The tip, leading edge, and trailing edge part definition routines define the detail parts making up the fixed leading edge, fixed trailing edge, slats, flaps, foreflaps, control surfaces (spoilers, ailerons, rudder, and elevators), and tips. The data that is generated includes the number of parts, part dimensions, weight, and cost parameters. The parts definition derives its input from previous geometry and analysis subroutines.

Computer Program

The program is computerized in a series of modularized subroutines, developed for the CDC 6400 computer and now operational on the 6600, to define geometry, perform structural analysis, and develop part definitions for aerodynamic surface leading edge, trailing edge and tips. A listing of these subroutines has been made available, separately.

5.3 COMPUTER PROGRAM FOR DEVELOPMENT OF F-N-L WEIGHTS

The Computer Program for Development of Aircraft Fuselage, Landing Gear and Nacelle Weights is newly developed under this contract for the synthesis of supporting data for fuselage primary and secondary structure, nacelles and landing gear cost estimating. Since it has not been previously reported, a complete description is provided as Appendix D.

As shown in Figure 20, this program uses as input the output of APAS. Thus the program is subject to any limitations imposed by APAS. Appendix D is in the form of a subreport (since the document has previously been issued as an internal report). It contains, as an appendix, a program listing describing the computer program used.

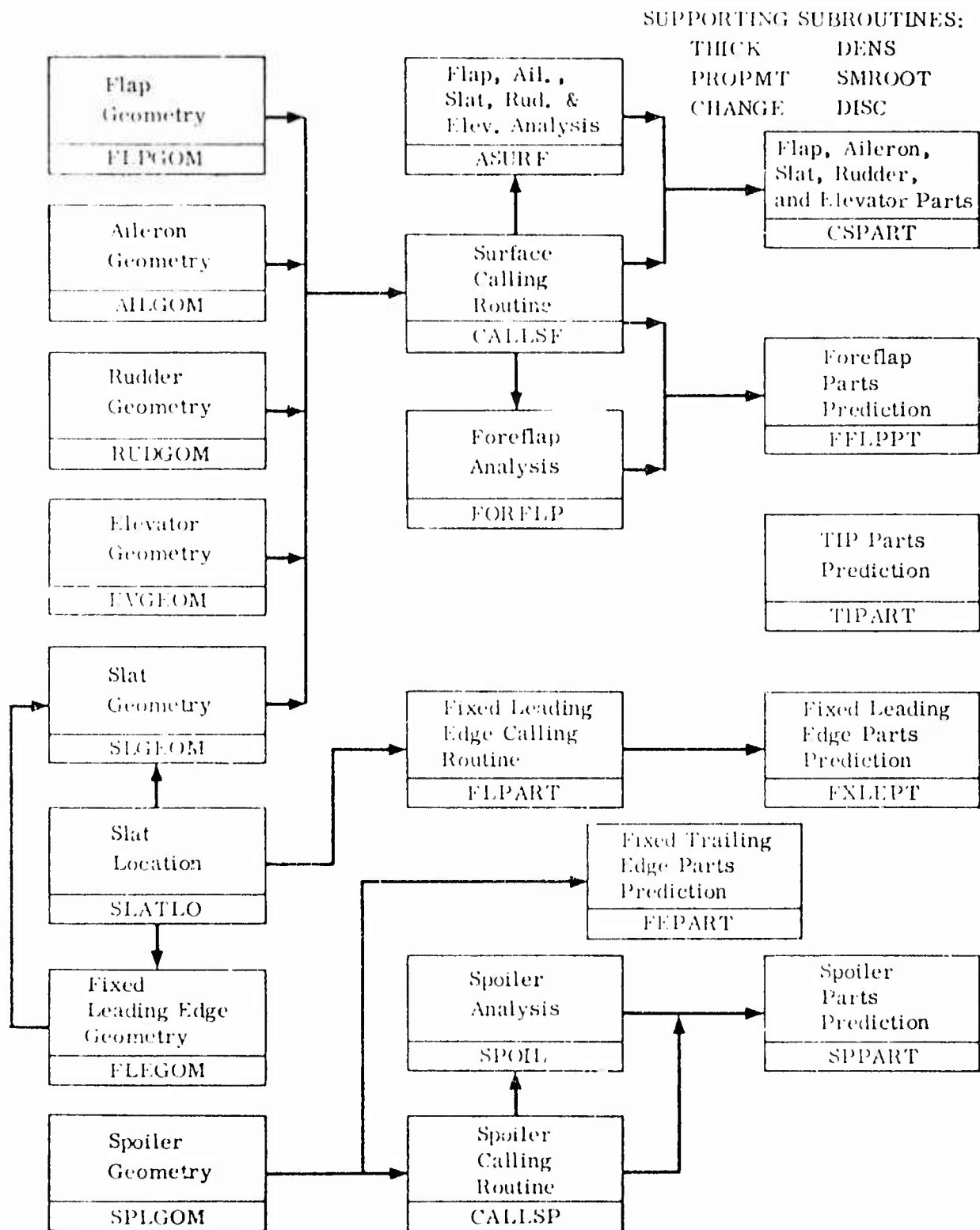


Figure 61. Secondary Structure Synthesis.

3.4 FINITE ELEMENT STRUCTURAL SYNTHESIS

The existing cost estimating technique is adapted to a multi-station structural synthesis approach, as has been described above. Use of this approach limits the capability of the estimating techniques since it relies on a beam analysis that is not applicable to all types of structure: delta wings and complex fuselages being examples of important exceptions. Finite element structural synthesis has been investigated during the course of this study as an additional mode of operation which it was hoped would provide enhanced structural analysis capability and an expanded cost estimating capability.

In general, structures can be separated into two classes based on the criteria of continuity and the existence of a reasonably well defined elastic axis. If a candidate structure has these characteristics, it may be modeled as a beam and the internal loads distribution calculated by well known beam theory and equations. This class of structures is successfully treated by multi-station synthesis programs. High aspect ratio wing and tail surfaces are typical examples.

The second class of structures cannot be characterized as beam-like either because of discontinuities, such as the cut outs found in fuselage structures, or the absence of an elastic axis typified by low aspect ratio surfaces, delta wings or plates. Internal loads for this second class of structures will not yield to solution by conventional beam theory. Finite element methods can, however, be used to predict the internal loads distribution.

The proper classification of a structure or the compromise in assuming that it falls in one class or another is not always obvious. There is a significant difference in the form and complexity of models for the two systems. Math models for multi-station synthesis are much simpler than those required for finite element methods. The finite element approach is far more general than the multi-station method and any structure amenable to synthesis by multi-station methods could be handled by a finite element program. The reverse, however, is not true.

From the standpoint of the development of cost estimating techniques the inability to deal with delta wings and complex fuselages is, of course, a significant limitation. Incorporation of a finite element synthesis procedure in the costing loop was considered at the inception of this study to be dependent upon a choice to be made in synthesis methods required and in the state of development of the finite element method. It was also recognized that the capability was more important to fuselage synthesis than to wing synthesis. Results of the study indicate that incorporation of the finite element method is beyond the scope of the present effort in terms of working out the cost estimating interface, in view of the further development of the synthesis method needed prior to its use, and in view of the additional development of weight correlation factors required for reconciliation of idealized and actual structural

weights. Use of the finite element approach also requires consideration of the question of compatible input data for the secondary structure weight analysis as currently used. Each of these problem areas is discussed below.

The state of its development and its suitability are key questions in the use of finite element synthesis in a cost estimating procedure. During the course of this study, an IRAD program has been underway to evaluate finite element structural synthesis approaches. A General Dynamics finite element synthesis program, coupled with a fully stressed resizing algorithm, was selected for demonstration. Several finite element programs were reviewed leading to the selection of the SR-7 program for the methodology demonstration. Characteristics of this program that favor its selection are:

- a. Overall level of refinement consistent with predesign task: The element library is adequate, various material options, boundary condition and external load definitions permit reasonable description of structures without encumbering the program size with seldom used features.
- b. Program Size: Computational costs are highly dependent on the local installation details. Core usage is almost always an independent variable in the cost algorithm. Three versions of SR-7 have been prepared that accept models of 160 nodes, 200 nodes and 340 nodes. This places some constraint on the amount of detail that can be included but it has been found to be adequate for most predesign tasks.
- c. Solution Efficiency: Computational time is another major independent variable in cost algorithms. The particular method used, a Gaussian decomposition, is one of the faster methods for solving systems of simultaneous equations.
- d. Familiarity with Program: A learning period is required by all finite element programs. Capabilities, special features and pitfalls cannot be properly appreciated without attempting a few applications. An in-house program has an advantage in this regard.
- e. Access to Source Deck: Ability to work directly with a source deck is highly desirable. The effect of changes can be quickly determined. Some programs are proprietary property of the authors and cannot be altered. Source logic is unavailable in some instances.
- f. Adequacy of Element Library: The types of elements offered determine the power of simulation of the model.

Two advanced designs, a delta wing and a complex fighter fuselage were used in the investigation. Models were prepared and run using approximately the

level of geometry and loads information available at the stage of design development that a synthesis program could be most profitably employed.

Illustrating that finite element structural synthesis is in the development stage, some characteristics of SR-7 were exposed that could be considered disadvantageous.

- a. Node Stability: The present program requires all nodes to be supported in three directions, either by structural members or boundary conditions. A dummy element can be used to overcome this instability but this introduces other disadvantages: the extra member to be analyzed is inefficient and there is no way to avoid a resizing loop.
- b. Number of Loading Cases: A maximum of four loading cases can be run. Since member information must be stored for comparison and summary purposes increasing the number of conditions would increase the required machine core. Extensive format changes would also be required.
- c. External Substructuring: The solution method relies on a "banded" stiffness matrix. The user must order the input properly and observe a limitation on the numerical node separation.
- d. Output Format: An option to limit or select the particular information of interest would be a useful feature. The present output is repeated for each member, for each load condition for each iteration and tends to overwhelm the user. Program termination is controlled by a preset number of iterations. Weight summaries for the first few loops and detailed information for the last two cycles would probably be adequate for most users.
- e. Documentation: Program SR-7 is an intermediate step in the continuing development of finite element synthesis programs, and while very useful as a developmental tool, it is not expected to be accorded production status or exist long enough to justify full documentation.

In general, structural synthesis using finite element methods for the distribution of internal loads can be applied to virtually any design configuration, and restrictions on the type of structure associated with multi-station synthesis are removed. However, model preparation and organization of input data are more complex tasks with finite element methods than with multi-station programs.

The process can be used to produce a rational distribution of structural material. Optimality of the design depends in part on the redesign algorithm. Trade studies may be conducted to study the effects of various material and geometric changes. Program operation is quite similar to conventional finite element analysis. Convergence to a theoretical structural weight is possible in two to three cycles.

Assumptions and simplifications introduced by the modeling process, particularly "lumping", reduce the visibility and detail that can be extracted for individual elements. It is possible to incorporate failure criteria that consider structural stability although a detailed model (or refined unlumping technique) is required to separate the elemental variables such as flange widths and thicknesses.

Other failure modes involving dynamic and flight safety criteria are extremely difficult to generalize. Studies are being done in these areas and ultimately methodology will be developed. Dynamics and flight safety specifications will have to be available early in the design cycle for proper integration with static strength requirements.

Computational costs are two to five times those of the multi-station process. Model preparation and coding of input data are also increased by approximately the same proportions.

Finite element synthesis development has benefited from prior work with multi-station programs. There are, however, major differences in some areas that will require additional research and development before finite element methods reach the same level of refinement now available with multi-station programs.

Finite element analysis programs are benefiting from continuous development and refinement. Features such as automatic organization of the element data to prepare the stiffness matrix for efficient solution are available in most of the recently released programs. In addition to relieving the user of this responsibility improvements are usually noted in total problem turnaround because a source of input errors has been eliminated. The actual mechanics of the computations are also being refined and processing times (and costs) are being reduced. It is felt that future development work should be based on an analysis package having these features:

Program Mix: User experience with finite element analysis programs has indicated that efficient processing is obtained if a library of programs is available. A mix of three programs of differing sizes and complexities appears to be adequate for the range of structural analysis problems that are commonly encountered. A similar philosophy should be considered for finite element synthesis programs. A program satisfactory for a typical predesign trade study should not be expected to produce highly refined design data.

Resizing: Resizing or redesign algorithms should be consistent with the program application. The fully-stressed design used by SR-7 is useful and generally adequate for predesign type work. Ability to unlump the structure and identify various elemental failure modes will be required for more advanced synthesis applications.

Failure Criteria: Failure criteria other than static strength requires a great deal more work. Philosophy and methods of failure identification for both flight safety and dynamic phenomena do not presently have the same definitiveness that has been developed for static strength. Similarly the appropriate corrective action for failure modes other than static strength are extremely difficult to generalize. Studies in these areas should be monitored for possible applicability to finite element synthesis procedures.

Element Library: Synthesis programs should have consistency between the redesign algorithm and the element library. If a fully stressed redesign strategy is to be used then a rather simple element library will serve. Since many aerospace structures use reinforced sheets in their construction, elements (axial and shear carrying) that could represent linearly varying stress conditions would prove useful. A pressure resistant panel or membrane is another possible library addition.

During the course of the study and application of the program to practical design problems several deficiencies were revealed. These items were of a general enough nature (as distinct from program peculiarities) to warrant inclusion in a list of recommendations.

Thermal Loads: Any future candidate should include the ability to compute loads introduced into the structure by thermal distributions.

Number of Load Cases: Each additional loading condition increases the run time and computational expense. Judgement is required to select the critical cases for analysis to a reasonable number. The demonstration program allows four loading conditions. Any future candidate should be capable of analyzing 6 to 10 loading cases.

Supports: A commonly made modeling oversight is the inclusion of mechanisms or unstable nodes in the structure. This frequently results from failure to provide proper model support normal to the plane of loading. In the actual structure such stiffness is supplied by member bending resistance. A typical example is a frame: applied and internal loads of interest are usually in the plane of the frame, some bending stiffness normal to this plane exists but it is not the concern of the analysis. Rather than abort the job a support could be automatically installed and reported. This would be more efficient than the installations of "dummy" members to provide stabilization.

Analysis of the program output indicates that useful design information can be produced. Component and total structural weights reflect the idealized structure but are acceptable for making design comparisons and trade studies. Problems arise, however, in reconciling idealized and actual structural weights. Weight correlation factors offer some possibility for use, although, if the structure is complex enough to necessitate analysis by finite element methods, general correlation factors are

not likely to be satisfactory. Thus a task of considerable magnitude is foreseen in developing a means of translating the theoretical weight produced by the structural synthesis program to an estimate of real weight. The exact nature and magnitude of this task is dependent upon the finite element program selected.

In considering the cost estimating support problem, the need for a structural synthesis capability beyond that afforded by the multi-station approach is much greater for the analysis of the fuselage than for aerodynamic surfaces. It is not clear, however, that the finite element method can successfully fill the void within the context of a pre-design process. Using a small number of nodes, while holding down the cost of the analysis, does not give resolution to structural details such as shapes, thicknesses and other dimensions that (as well as the aforementioned uncertainty in weight predictions) play a part in costing. Increasing the scope of the analysis by identifying additional node points increases the program cost as well as requiring additional design information for node identification. Modeling can be accomplished for local load conditions. This gives rise to additional program runs and additional output data but still only defines cross-sectional areas. Future developments in finite element synthesis may alleviate objections, and the monitoring of development progress for possible future incorporation is suggested.

SECTION VI

METHOD DEMONSTRATION

6.1 OBJECTIVES

Trade study and system study test cases were estimated. In each case the test case aircraft was the B-58. The test cases were part of a required method demonstration. This demonstration was to include:

- a. The test case estimates
- b. Installation of the computer program on AFFDL's CDC 6600 computer at Wright-Patterson Air Force Base
- c. Presentation of the method and instruction of interested personnel in programming and execution.

The installation at AFFDL has been accomplished over a period of time by personnel of the Cost and Weight Analysis Group, Structures Division, with the contractor supplying the necessary programs and assist.

On 13-14 February 1975 a two-part final presentation on the contract was made. The first part was a summary, overview presentation on the results of the cost model that has been developed. The second part was designed for individuals who were interested in the mechanics of the models and the computer program. Test case results were also discussed as part of that presentation.

The objectives of the test cases can be summarized as:

- a. Debugging of the computer program.
- b. Verification of the estimating logic.
- c. Providing a reference for the coordination of the installation at AFFDL.

6.2 SELECTION OF TEST CASE

Originally it was planned to perform test case estimates of two different types of aircraft. This was reduced to one because of a desire to minimize the reduction to the cost data base and because of the cost involved in developing the necessary input data. The principal criteria in the test case selection was:

- a. The availability of technical data.
- b. The availability of cost data.
- c. The need for it to be one of the contractor's own aircraft.

Choice of the B-58 was supported by the availability of results from a NASA-funded cost data study, Reference 15. Technical data for the B-58 program were obtained from four general sources: (1) B-58 Cost Data Study Report, Reference 15; (2) B-58 Cost History; (3) Actual Weight and Balance Report for B-58A (Bomber Airplane), FZW-4-038, Reference 16; and (4) other internal company data sources. The B-58 Cost History is a specific internal document prepared as part of the company's ongoing cost research.

Other candidates were considered but were not selected for various reasons. The F-111A was a candidate, but the cost of collecting comparative actual data was beyond the budgetary limits of the study.

Test case estimates have been performed for each of the two estimating methods using the cost model computer program and the results from runs of the supporting synthesis programs, in the case of the trade study method. Printouts from these runs have been used to illustrate the methods in this volume and in Volume II. The steps taken and the information gathered in setting up the demonstration runs is described in Volume II, Section IV.

The results of the trade study and system runs cannot be directly compared since they are set up in different time frames: the trade study method estimates historical costs using a composite, then year labor rate, whereas the system cost estimate is made in 1974 dollars. The trade study method estimates labor and material separately, so that by applying the appropriate labor rate and material cost factor, economic escalation is taken into account. Some ambiguity occurs in the case of material cost, however, since the historical data typically intermingles production material associated with structure and purchased parts associated with the functional subsystems.

15. "B-58 Aircraft Cost Study for NASA, Manned Spacecraft Center," General Dynamics/Convair Aerospace Division (FWO), Report FZM-5934-1, dated May 1972.

16. "Actual Weight and Balance Report for B-58A (Bomber Airplane)," General Dynamics/Fort Worth Division, Report FZW-4-038, dated 1 May 1961.

The system cost estimating factors were developed from a data base that had been adjusted to 1970 dollars. An inflation adjustment was applied to these results to convert to 1974 dollars. Going back to the 1970 data base, or any intervening year, requires only a simple series of F-card changes. However, moving back to any earlier period would require a more comprehensive adjustment to the data base.

For the usual estimating situation, estimates will be made in the current time frame, and comparisons of the results from the methods can be made. Making a comparison in the case of the B-58 would be time consuming and still not conclusive due to the difficulties in determining precise escalation adjustment factors.

The demonstration cases as presently set up provides a comprehensive test of both methods. An analysis of estimates and a comparison to actuals, both from the B-58 aircraft and other aircraft, at subsystem and detailed levels, has been accomplished and is reported in this volume.

6.3 TRADE STUDY COST ESTIMATE - INPUTS AND RESULTS

One of the purposes of Volume II was to describe how to make an estimate using the two methods. To that end a description of the method, a set of input tables and the resulting estimates for the B-58 test case are shown in that volume. A complete set of estimates are given. Various parts of the estimate are used for illustrations so that the set appears throughout the volume. A table, Table M-1, locating each of the items of output data is given in Appendix M of Volume II. The NAMELIST variable input values used are shown in the form of a computer printout in Appendix B with a dictionary of variables in Appendix D (Both Vol. II).

The steps involved in developing input data are outlined in Volume II, Section 4.1. Input development, although prescribed, involves some element of judgment or special study. For example, the development of inputs for the test case included a review of the technical details of the basic structure based on information contained in Reference 15. Judgment is also involved in the application of labor rates. In the usual procedure, it would be necessary to project these into a future time frame requiring an estimate of the values. For the test case it was necessary to estimate the time reference for the empirically derived labor rate.

In evaluating estimating results it would have been desirable to make comparisons at the detailed level of the various estimating formats referenced in Table M-1. This was not possible inasmuch as actual data was not available at that level of detail. The following comparisons have been made, however:

- a. First unit manufacturing hours at the subsystem level.
- b. Basic structure design engineering hours at the subsystem level.

- c. Tool manufacturing hours at the subsystem level.
- d. An example of a detailed comparison for rib detail fabrication hours, B-58 to other aircraft.

The first of these comparisons is shown in Figure 62. The subsystems compared are the wing (W), the fuselage (F), the nacelles (N), and the vertical stabilizer. The symbols (A) and (E) represent actuals and estimates, respectively. Parallel lines illustrate the scaling assumed in the CER. Estimates are lower than actuals in each case except for the vertical stabilizer. This same data plus the percentage that the estimates vary from the actual is shown in Table 9.

Table 9. Estimates and Actuals for First Unit Manufacturing Hours.

Hardware Element	Weight (Lbs.)	Actual Hrs.	Estimated Hrs.	Estimate/ Actual
Wing	12,080	327,577	304,631	.93
Vertical Stabilizer	1,346	33,275	40,692	1.22
Fuselage	5,174	365,628	247,164	.68
Nacelles	4,675	171,837	149,251	.87

The second comparison for basic structure design engineering is given in Table 10. At the total basic structure level the correlation factor of estimate to actual is very good. However, considerable variation is noted at the subsystem level.

The comparison for tool manufacturing hours is shown in Table 11. Less variation is evidenced. It was felt in both of these cases that the data base was not sufficiently large to warrant the use of formal statistical measures of predictive error.

An example of a detailed level of comparison is shown in Figure 63. A series of such comparisons was made where the detailed estimate for the B-58 is compared to the unadjusted actuals for the same elements of hardware from other aircraft programs.

6.4 SYSTEM STUDY COST ESTIMATE - INPUTS AND RESULTS

The steps involved in developing input data for the test case are outlined in Volume II, Section 4.2. Appendix K, Volume II, contains a printout of inputs used and a

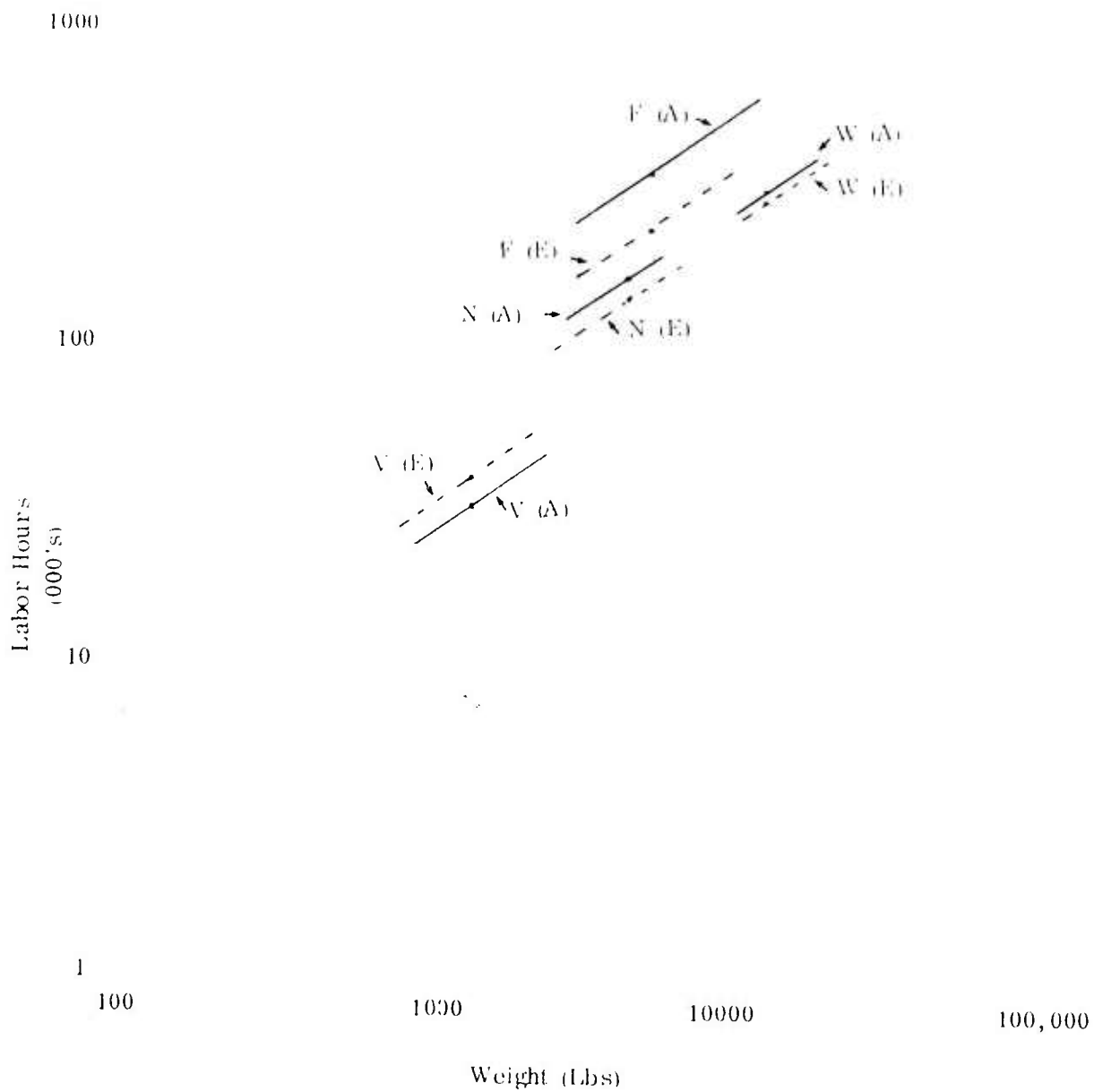


Figure 62. Demonstration Results - First Unit Manufacturing Labor Hours.

Table 10. Basic Structure Design Engineering -
(To First Flight)

	(Millions of Hours)		Estimated/ Actual
	<u>Actual</u>	<u>Estimated</u>	
Wing	.547	.327	.60
Vertical Stabilizer	.084	.062	.74
Fuselage	.275	.432	1.57
Nacelle	.199	.297	1.49
Landing Gear	<u>.19</u>	<u>.17</u>	<u>.89</u>
Totals	1.295	1.288	.99

Table 11. Tool Manufacturing -
(Millions of Hours)

	<u>Actual</u>	<u>Estimated</u>	Estimated/ Actual
Wing	2.01	2.1	1.04
Vertical Stabilizer	.25	.17	.68
Fuselage	2.2	2.08	.95
Nacelles	<u>.81</u>	<u>.98</u>	<u>1.21</u>
Totals	5.27	5.33	1.01

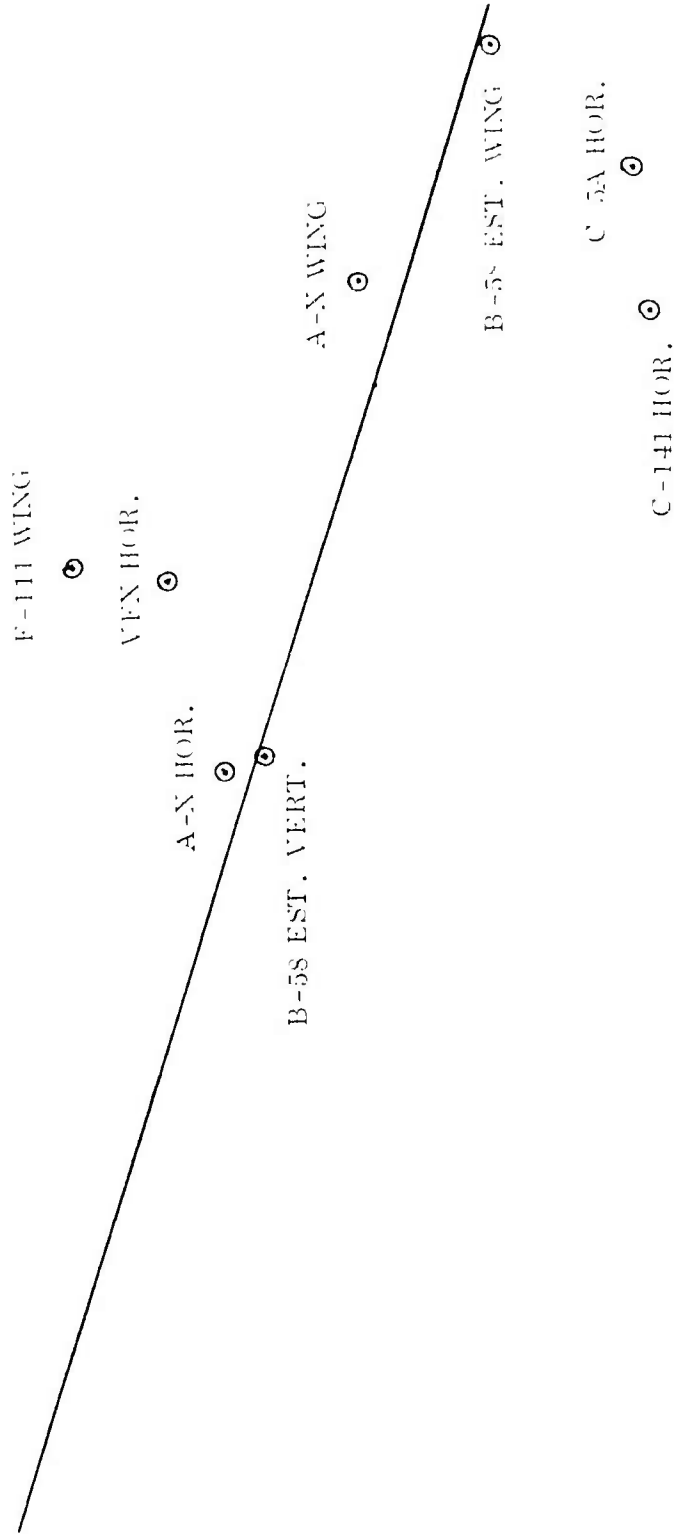
NAMelist variables dictionary for each of the categories of cost estimated.

Possible comparisons of estimates to actuals are more limited in the case of system cost estimates because these have included an escalation factor to bring the results towards what current costs would be. First unit manufacturing costs are estimated

100

lbs./lb.
10.

143



1
1

10
Weight

1000

Figure 63. B-58 Estimate - Rib Detail Fabrication.

in dollars, combining labor and material, escalated to 1975 dollars. Also, level of detail is the subsystem eliminating the comparison at the component level. This leaves for comparison engineering and tooling hours.

In the case of engineering there are differences in method between trade and system. In the first the CER form is based on equation (23) of the trade study series. The term EH is defined as the product of an estimating coefficient and a complexity factor and the application of complexity is external to the model. EH is a NAMELIST variable. In the case of the system method, the CER is based on equation (1) of that series; and both a complexity factor, as a NAMELIST variable, and an estimating coefficient, as an F-card input, are used. For the system estimate an estimate of B-58 complexity was introduced. Configuration design engineering, although defined the same in both cases, is estimated differently depending on the definition of the airframe.

Estimated to actual engineering hours compare as follows:

	<u>Actual</u>	<u>Estimated</u>
Engineering hours to end of development:		
Structures (incl. Support)	2,690,000	
Engineering hours to 1st flight:		
Basic structure		1,250,462
Allocated Support Engineering		<u>1,000,000</u>
		2,250,462
Estimated to end of development:		
1st flight times 1.4		3,150,000
Percentage variation: $\frac{\text{Predicted}-\text{actual}}{\text{Actual}}$ or $\frac{3,150,000-2,690,000}{2,690,000}$		17%

In the case of tooling, the differences in method are similar to those in engineering. Tooling estimates are developed from an initial estimate made for basic tool manufacturing hours. Rate tool manufacturing, basic tool engineering and rate tool engineering hours are derived as factors of that initial estimate. This CER is based on trade study equation (28). The term TMF is defined as the product of an estimating coefficient and a complexity factor, which in the case of the system method are explicitly defined (from system method equation (8)). Table 6 has been developed for TMF values for use in the trade study method. Use in the system method of the set of values at complexity 1.0 (regular supersonic) as the estimating coefficient and the appropriate complexity factor gives the same estimating results as for the trade study method.

SECTION VII

OTHER STUDIES

A series of sub-studies was a part of the contractual requirement. These studies were separable from the mainstream effort and are reported in this section.

7.1 APPLICATION OF INTERACTIVE GRAPHICS

Interactive graphics has been investigated for application to each of the estimating methods. It does not appear to be relevant to the system costing method because this method is used for costing of point designs rather than in an iterative mode and because it is not tied into supporting synthesis programs, where the greatest potential for its application is believed to lie.

In the case of the trade study estimating method, consideration of its application is felt to be premature for the same reason that computer integration has been kept on a manual basis: the program is still in a formative stage and stand alone operation simplifies changes to the various programs. Upon attaining a completely integrated cost estimating program, interactive graphics should be considered in view of the following benefits:

- a. Graphical or pictorial displays of input data, intermediate results, and final answers.
- b. Pre-stored messages to direct the user.
- c. The cost analyst and the designer, together, can converse directly with the computer during the design process.
- d. The problem solving process is highly responsive and can be conducted in an uninterrupted manner.
- e. On-line data retrieval.
- f. The user can concentrate on problem solutions rather than computer-related difficulties.
- g. Input errors are not fatal since the data base can be reviewed and modified from the terminal.
- h. Problem solving time and cost are reduced.

In the mean time a time-sharing mode of operation, such as Control Data's INTERCOM, provides a capability that is particularly useful in relation to the basic estimating concept: that estimating coefficients may be subject to change as an ongoing part of the development of the estimating capability. A time-sharing mode permits an expeditious handling of such changes by permitting recall and display of any model card of the input data and by providing a simple means of changing the recalled card at a convenient terminal. The precise nature of the time-sharing system used depends upon available equipment. The Control Data Corporation INTERCOM system, operating in conjunction with SCOPE, provides time sharing access to the CONTROL DATA CYBER 70/Model 72, 73, 74, or 6000 Series Computer from a terminal at the central site or at a remote facility. The capabilities of INTERCOM include:

- a. The ability to create, edit and save programs by entering source statements at the terminal in any of various languages.
- b. The ability to execute programs interactively: input can be typed, output can be looked at on terminal.
- c. Jobs can be submitted to input queue for output on central printer, punch and tape or output to terminal.
- d. Files can be routed to print or punch queues at central.
- e. Most SCOPE control cards can be entered from terminal file manipulation.
- f. On-line graphics can be provided by Tektronics 4010 equipment; off-line graphics by Calcomp plotter.

The estimating system, as installed at AFFDL, makes use of a time-sharing system.

7.2 OPERATING COST RELATIONSHIPS

The scope of this task was changed to focus on the question of determining the translation of weight savings to fuel savings in a life cycle context, weight savings being a possible consequence of the selection of material and construction type. Other areas of interest in the study were the relationship between changes in type of material and construction and operating cost items such as on-equipment maintenance, off-equipment maintenance, and replenishment spares. The data base needed to investigate these latter items has been determined to be beyond the resources of this study.

The translation of weight savings to fuel savings can occur in two ways: with and without resizing. If resizing is to be considered this problem cannot be solved by the existing trade study programs. The majority of the subsystems can be affected,

including engines. This case is shown in Figure 64.



Figure 64. Resizing Effect.

Without resizing the effect of a weight reduction can be measured by assuming that all variables except range remain constant, then determining the improvement in range, and then stating a fuel savings ratio as the original range to the improved range. The actual fuel savings cannot be determined from this, however, without knowing certain characteristics of the specific aircraft involved.

Improvement in range can be determined by the Breguet range equation, which is written as

$$R = \frac{V_t (L/D)}{C'} \ln (W_o / W_1)$$

where

- R = Range km (nm)
- V_t = True airspeed km/hr (kt)
- L/D = Lift-to-drag ratio
- C' = Thrust specific fuel consumption kg/N-hr (lbs/lb-hr)
- W_o = Initial cruise gross weight kg (lb)
- W_1 = Final cruise gross weight kg (lb).

This equation is applicable only to cruise flight with the difference between W_o and W_1 being the weight of fuel used in flying the distance, R . If, however, this equation is solved a second time for a range, R_1 , defined as the range resulting from a reduction in structural weight, the fuel savings is proportional to the term $(1 - R/R_1)$.

The same solution can be applied to a final structural and aircraft weight reduction if this has been determined through an aircraft resizing. However, the before and after values of V_t , L/D , and C' must also be known.

If the cruise fuel weight is known, then a fuel weight per mile can be determined for the initial condition, range R , and for various improved ranges between R and R_1 to

to produce a plot as illustrated in Figure 65.

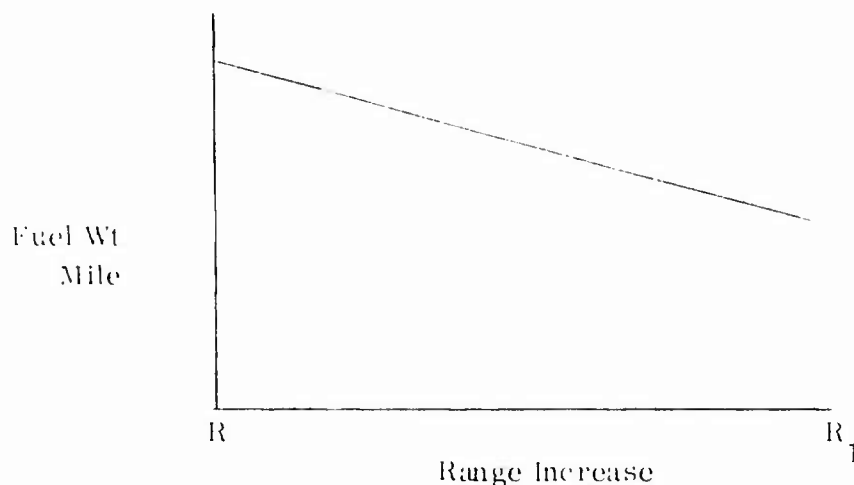


Figure 65. Fuel Weight/Mile with Range Change.

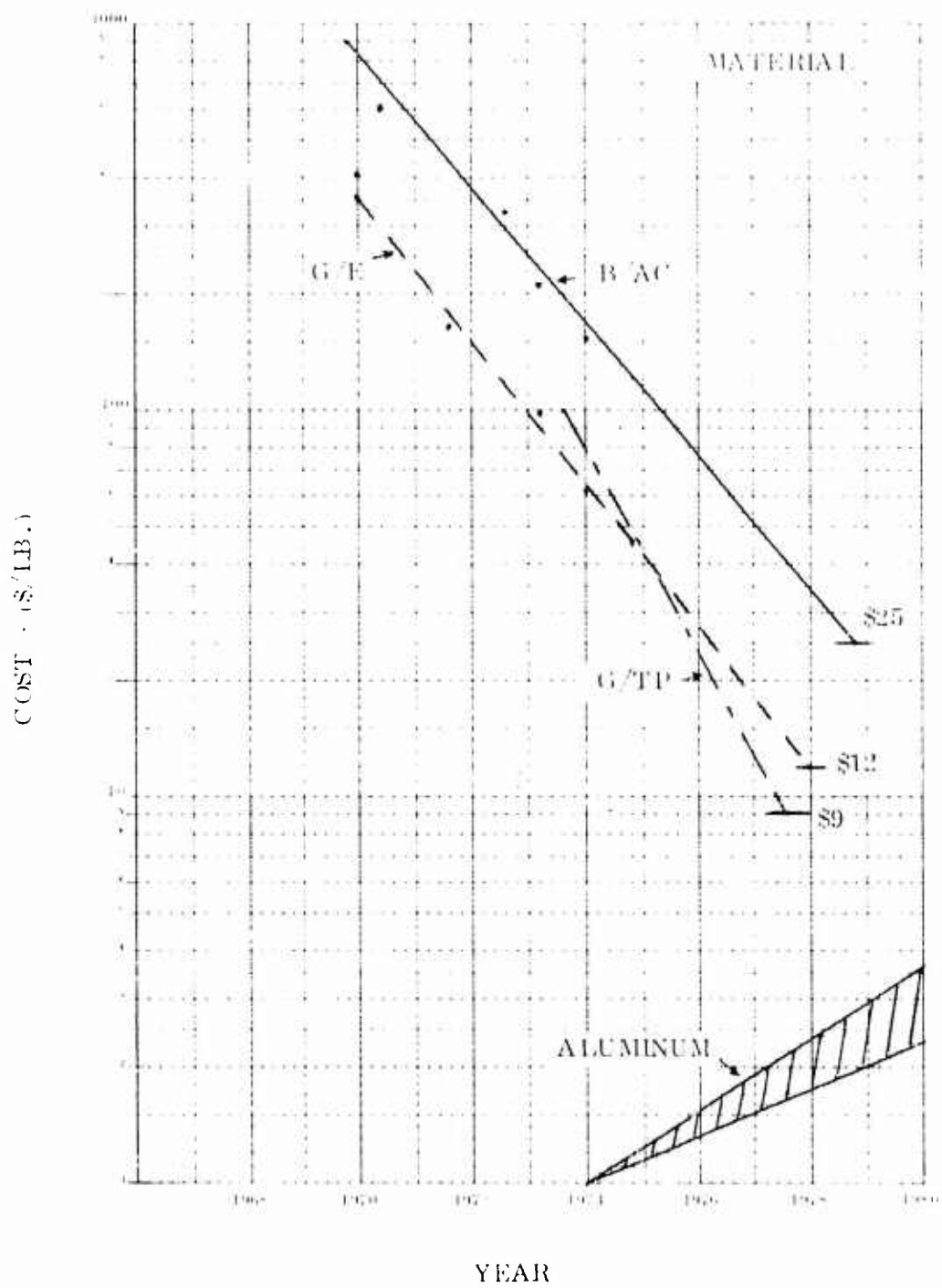
7.3 ADVANCED STRUCTURES AND MATERIALS

This study considered advanced structures and materials in the following ways:

- a. By the development of additional estimating factors to handle advanced materials and construction techniques.
- b. By the development of projections of raw material costs for typical composite materials.
- c. By the development of cost estimating relationships to estimate the cost of using composites as selective reinforcements to basically metallic structures.

The estimating factors that have been developed consist of complexity factors and are included in the estimating factor tables for secondary structure contained in the Estimating Handbook volume. Efforts to develop similar factors for primary structure have been limited because of the lack of a historical cost data base. Various secondary structure components made with boron aluminum and graphite epoxy have been analyzed, such as wing leading and trailing edges, ailerons, fairings, spoilers, flaps, access doors, wing mounted air induction, slats, center sections and elevators and rudders.

A raw material cost history for boron aluminum and graphite epoxy (diffusion bonded sheet and tape respectively) and a projection of future costs are shown in Figure 66. This is contrasted to the projection for aluminum. While the projection is for cost against time, level of production attained is the real determinant, but this can



Note: G/TP & G/E prices are the same except for scrap return allowance (50% scrap at 50% return cost).

Figure 66. Composite Material Cost Projection.

generally be assumed to increase with time.

A method for estimating the cost of using composites as selective reinforcements to basically metallic structures was reported in Reference 1. This method remains applicable to the general trade study method as currently defined. In it, an increment of added cost is estimated in terms of additional detailed fabrication and sub-assembly labor and composite material costs for primary structure and of labor and material for secondary structure. Detailed fabrication labor for primary structure is estimated on a weight basis: the weight of composite material to be used. This is multiplied by a factor to take into account the type of composite involved. Sub-assembly labor for primary structure is estimated on the basis of the area involved. Both categories of labor are estimated on the basis of weight in the case of secondary structure. The cost of the production material for the selective reinforcement, whether for primary or secondary structure, is estimated as the product of the scaled value of the composite material weight times an aggregated cost per pound value, reflecting the basic material cost plus an allowance for scrappage, handling and storage.

The principal limit to estimating the cost of composites with the present method lies with the stress analysis capability encompassed by the APAS program. Currently this capability is limited to composite faced sandwich for skin panels and to composite material with metallic structural forms in the case of basic primary structure forms: ribs, frames, spars, longerons and bulkheads. The programmed material table for metallic forms includes NARMCO 5505 Boron-Epoxy and NARMCO 5206 Graphite-Epoxy. In addition, the program provides for a user supplied composite material, allowing the program user to input a composite material not found in the material table.

Existing weight correlation factors are invalidated by the use of composites. Additional studies are required to develop factors that are representative of composite structures. The present estimating method, as it relates to cost estimating relationships, handles composites with the following limitations:

- a. The limited nature of the historical cost data base, which consists primarily of items of secondary structure or experimental hardware in the case of primary structure.
- b. If the use of composites serves to introduce new types of construction such categories are not necessarily handled, especially in considering assembly operations.

Designing a new or modified model for handling composite materials would involve:

- a. Developing advanced means for handling stress analysis.

- b. The additional collection of cost data.
- c. Development of appropriate weight correlation factors.
- d. Identification of new types of construction and corresponding revision of cost estimating relationships, estimating coefficients, scaling relationships and complexity factors.
- e. Assessing the impact of the composite materials and new types of construction on learning progress curves.

The degree of success in handling composites with a new or modified model can be assessed in relation to the above activities.

The stress analysis, as handled by the supporting synthesis programs, is considerably complicated by the introduction of composite materials. The recommended approach is a feasibility study looking into the types of construction to be projected and the feasibility of stress analysis approaches, which would involve both beam analysis and finite element analysis. It is expected that these approaches can be developed, but the resources required and the complexity of the resulting model must be assessed.

Relevant cost data is becoming increasingly available, although of course, extensive production experience is lacking. Experimental hardware is being increasingly evaluated from the standpoint of cost. Examples of such studies are shown in Table 12. This list is not a complete list, but is being added to during the course of this study. Applications of composites and the attendant data are in large part proprietary, limiting its usability. Also, in some cases, the data reflects the advocacy position of the analyst.

Development of weight correlation factors would be a sizable task in and of itself. Definition of the task and estimates have not been undertaken.

The use of composites complicates the definition of types of construction. With metallics these definitions are somewhat ambiguous, and with composites they would be even more so. Types related solely to composites will undoubtedly be developed, but the use of composites in combination with metallics is also in evidence. The revision of cost estimating relationships, the development of estimating coefficients, the reassessment of scaling relationships, and the development of complexity factors appears feasible for composite structures but is at least as involved as the original task with metallics.

The treatment of learning curves has not been part of this study so that future study should encompass both metallics and composites. The analysis of the effect

Table 12. Composite Material Studies.

Title	Sponsoring Agency	Contract or Source of Funding	Description and Data Expected
Preliminary Weight and Cost Estimates for Transport Aircraft Composite Structural Design Concepts	NASA	NAS 1-10702	Advanced Technology Transport systems studies for commercial transport aircraft, containing major structural applications of advanced composite materials.
Boron/Aluminum Composite Evaluation	IRAD	CASD-ERR 73 019	Proprietary. Study to evaluate the cost posture for boron aluminum between the mid-1970's and mid 1980's. Projections of boron aluminum raw material costs.
Improved Manufacturing of the F-14A Composite Horizontal Stabilizer	--	--	SAMPE Quarterly, April, 1974. Report on Manufacturing process improvements.
Conceptual Design of Advanced Composite Airframes	Air Force	F33615-72-C-1424	Fort Worth Division study for the application of advanced composite materials to the lightweight fighter. Cost comparisons and flyaway cost sensitivity.
Advanced Composite Applications for Spacecraft and Missiles	AFML	F33615-70-C-1442	Study of OV1 missile support system structure. Considered diffusion bonded Borsic aluminum, graphite epoxy, boron aluminum and graphite epoxy. A materials and process development program is reported. Weight and cost data are estimated.
Low-Cost Manufacture of Composites and Fabrication of Boron/Aluminum Tubes	IRAD	1974	Cost reduction study for fabrication of boron aluminum tubes.
Low-Cost Composite Processing	IRAD	1974	Investigation of new processes that will lead to lower costs for boron/aluminum and graphite epoxy structures.

Table 12. Composite Material Studies (Continued)

Title	Sponsoring Agency	Contract or Source of Funding	Description and Data Expected
Advanced Composite Material Technology	IRAD	1974	Evaluation of graphite epoxy and graphite polyimide composite systems applications to thermally stable structures and to high temperature uses and to investigate potential adhesive systems.
Development of Graphite Reinforced Thermoplastic Technology	IRAD	1974	Investigation of cost savings inherent in applying thermoplastic technology to graphite reinforced thermoplastic composite systems.
Advanced Development of Not-Critical-to-Flight-Safety Advanced Composite Aircraft Structures	AFML	TR-74-38	Design, fabrication and cost analysis of F-5E trailing edge flap and the A-9A rudder.

of learning on manufacturing cost is further complicated with composites. New manufacturing processes are involved, and additional data will be required.

Based on the above, it is felt that the trade study cost estimating method can be modified to handle composites with a reasonable expectation of success. Considerable additional study is required to develop the necessary cost data base, which must be proceeded by further design and manufacture to reduce uncertainty. Weight correlation and estimating factor development gradually become feasible. The most time consuming aspect is attaining the capability for stress analysis in a manner that also provides adequate design visibility. A separate study of feasibility is probably warranted in this area.

7.4 COST TREND DATA

As a part of the study the contractor was to develop plots of total aircraft and air-frame cost trend data and cost per pound factors to support the cost estimating technique, to show trends in costs and to show various cost relationships, such as cost related to time, cost related to various weights, and cost per pound factors for manufacturing costs of major structural components. The development of cost trend data was divided into four general areas outlined as follows:

- a. Plots of whole aircraft and/or AMPR structure costs versus various aeronautical design or performance parameters.
- b. Plots of aircraft costs as a function of time or economic factors.
- c. Pie-charts of aircraft development program costs as functions of quantity produced and aircraft system complexities.
- d. Plots of structural cost versus weight for fuselage, wing and tail sections structures.

A complete report on the results of this study are included in Volume III, Reference 2.

SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

1. The trade study costing methodology, designed to systematically estimate cost variations due to changes in type of material and type of construction, has been applied to the entire basic structure. The method has been shown to provide a feasible approach to trade study costing for structural design-to-cost problems during preliminary design. The resulting cost model makes estimates based on physical parameters, type of material, and type of construction and assembly of structural components such as ribs, spars, covers, longerons, frames, etc. The model is still considered to be in a developmental status and the following additional studies are recommended.
 - a. Extension of the cost data base (1) to provide data for missing components and (2) to extend the data base into advanced type structures.
 - b. Further test and evaluation of the method for further familiarization and to eliminate program discrepancies.
 - c. Improvements in certain specific cost estimating relationships in the areas of raw material costs, assembly modeling, commonality, and the treatment of advanced structures and composites.
 - d. Performance of additional estimating runs using the updated method to further calibrate estimating coefficients and to evaluate estimating capability.
2. The trade study cost estimating method establishes a format for the future collection of cost data. Method development has been primarily structured to the concept of unlimited data, i.e., to a cost data collection format that would prevail in the future rather than being limited precisely to an existing historical data base. Continued cost data collection is a necessary part of further development of the method. A number of ongoing studies arising out of the Air Force Flight Dynamics Laboratory's sponsorship of Advanced Development Program warrant monitoring. Continuing literature review and an interchange of data with other contractors are also possible sources of additional data.
3. Certain specific trade-study model improvements suggest themselves:
 - a. Modification of the estimating logic to provide for determining the sensitivity of recurring cost to production rate.

- b. Development of data to show variation in learning due to type of material and type of construction.
- c. Incorporation of additional calculations to provide a readout of the dollars ²/lb. and hours ²/lb. implication of a given estimate.

These were not part of the current study, but their accomplishment would add to the performance of the model.

4. Providing a capability for estimating alternative production quantities to the same level of detail as that provided for estimates of first unit cost has been shown to be a useful feature. It is especially important in considering learning curve variations for trade study purposes. The model does provide for the use of individual cost-quantity projections by structural element within the fabrication, subassembly, and material cost categories.
5. Two additional features, (1) the inclusion of an additional term in certain CER's to give consideration to internal structural commonality and (2) the consideration of taper in the machining of parts in the development of complexity factors, should continue to be considered for incorporation in the method. The first requires additional study to determine the proper approach and the second requires additional cost data.
6. Iterative estimating methods at a detailed level of cost breakdown have been shown to be feasible. Their accomplishment is dependent upon supporting input data from structural synthesis and weight sizing programs, however. Further improvement in these programs is warranted:
 - a. Improvement of the Computer Program for Development of Aircraft Fuselage, Landing Gear and Nacelle Weights in its weight estimating methodology.
 - b. Expansion of the Tip, Leading Edge and Trailing Edge Analysis program to handle additional types of material and construction using techniques other than analog.
 - c. Continued improvements in APAS for enhanced sensitivity to structural considerations.
 - d. Development of finite element synthesis programs should be monitored. Future developments in this approach may alleviate current objections and provide useful (from a cost-estimating standpoint) design synthesis.
 - e. A combination of multistation and finite element synthesis programs warrants further investigation.

7. In addition to further exercising the cost model portion of the overall program, the total program, including supporting synthesis programs, should be operated to provide guidelines for future improvement and also to establish guidelines for using the combined programs in design to-cost trade-off studies in a preliminary design context.
8. The principal functions of the system study cost estimating method as currently developed is to provide a more complete set of costs for possible comparison against the airframe portion of flyaway cost and to provide an interim costing capability in the preliminary design process so that estimates can be made prior to the availability of a complete set of detailed, trade study inputs. A dual mode of operation has been defined for this purpose.
9. The cost model is computerized using a general, data manager program referred to as COSTC. A significant feature of this program is that it provides for handling the cost estimating relationships as input data, which provides a considerable degree of flexibility in revising CER's and cost estimating coefficients.
10. Estimating the cost of contemporary and future aircraft designs generally involves consideration of advanced types of construction and material. Some factors for these have been developed for use in the method. The level of detail entailed in the trade study method provides an approach to this problem, being suited to the evaluation of individual problem areas that can not be accomplished by the usual parametric means.
11. Considering the evolution of design-to-cost, in the future cost may be defined as life-cycle-cost. In this case operating cost and the inter-relationship between it and structural design will be a trade study consideration. Attempts were made to study such interrelationships, but available operating cost data does not lend itself to such an analysis. An expansion of the scope of the study is indicated.
12. The B-58, A(X) and Model 880 fuselages were run as test cases in the development of the fuselage module. A series of APAS runs was made to provide the input data for the fuselage, nacelle and landing gear weights program, which was in turn run to provide weights data. Test case inputs and outputs for this program are given. Resulting cost estimates were analyzed and used in evaluating baseline cost estimating factors. The computer printouts obtained are not reproduced in this report, but have been retained. These results are not of current interest because of changes that have occurred both in the program and in the estimating coefficients.

13. The B-58 was used in the test case of both the trade study and system study methods in their complete form. These estimates are reproduced in Volume II with the location of the data given in Table M-1.
14. This cost model has been developed in response to a recognized need for a cost model sensitive to variations in the materials and type of construction in a particular design. The need is in relation to trade studies to evaluate the impact on cost of using advanced technologies in structure and materials. More recently the Design-To-Cost approach in the acquisition of new weapon systems has increased the need for models of this type. The additional developments outlined above, including the experience gained from use, will greatly enhance the program.

APPENDIX A

TRADE STUDY CERS AND DEFINITIONS

This appendix consists of a listing of basic CER forms and the accompanying set of cost definitions. Two numbering series are used to cross-reference these CER forms to previous descriptions: (1) the first column which references a series of figures depicting cost printouts and identifying the corresponding CERs, and (2) the second column, which references the assignment of equation numbers used in Volume II. In the case of the first column, the figure cross-reference is as follows:

- | | | |
|-----------|---|---|
| Figure 21 | - | First Unit Cost |
| Figure 32 | - | (Wing) RDT&E Costs |
| Figure 33 | - | Nonrecurring Design and Development Costs |
| Figure 36 | - | Recurring Airframe Production Costs (Summary) |

where

$$H_i = \left[\frac{W_i CM_i + W_i CM_i + W_i CM_i}{W_i CM_i + W_i CM_i + W_i CM_i} \right] HF_i + W_i CM_i$$

- H_i subassembly hours for ribs, frames, spars, longerons and covers corresponding to variable inputs
- W_i a series of weights for ribs, frames, spars, longerons and covers related to subassembly labor
- CM_i a series of composite unit costs for ribs, frames, spars, longerons and covers related to subassembly labor
- WT_i composite unit cost of weights
- WT sum of rib weights
- $W1$ sum of rib weights
- $W2$ sum of rib weights
- $W3$ sum of rib weights
- $W4$ sum of rib weights
- HF_i a series of reference unit cost for ribs, frames, spars, longerons, and covers related to subassembly labor
- F_i a series of weight related components for ribs, frames, spars, longerons, and covers related to subassembly labor

Subassembly Hours for Rib, Frame, Spar, and Cover

$$H_i = \left[\frac{W_i CM_i + W_i CM_i + W_i CM_i}{W_i CM_i + W_i CM_i + W_i CM_i} \right] HF_i + W_i CM_i$$

- where
- H_i subassembly hours for ribs, frames, spars, longerons and covers corresponding to variable inputs
- W_i weights used for detail labor
- CM_i a series of composite unit costs corresponding to component type related to a sample
- WT_i composite unit cost of weights
- WT sum of rib weights
- HF_i a series of reference unit cost for ribs, frames, spars, longerons, and covers related to subassembly labor
- F_i a series of weight related components for ribs, frames, spars, longerons, and covers related to subassembly labor

where H_i is the subassembly hours for ribs, frames, spars, longerons and covers corresponding to variable inputs

where H_i is the subassembly hours for ribs, frames, spars, longerons and covers corresponding to variable inputs

Fig. 1. Structure of the system.

Table 1. Structure of the system.

$$H_1 = \left[\begin{matrix} WT_1 & HSA1 & HSA2 & CN & RN & SNI & SNI^2 \end{matrix} \right]^T$$

where

- H_1 - primary structure matrix - assemblage of structural beams and columns structure;
- WT_1 - weights used in total load matrix;
- $HSA1$ - assembly hours per unit weight for transferring additional material;
- $HSA2$ - assembly hours per unit assembly for transferring additional material;
- CN - number of columns;
- RN - number of ribs or frames;
- SNI - number of sections;
- SNI^2 - number of internal joints or corners;
- Q - quantity of material;
- 2 - operator for determining surface area.

Table 2. Structure of the system.

$$H_1 = 2 \left[\begin{matrix} SPH & RP & H1 & T3 \end{matrix} \right]^T$$

where

- H_1 - hours for unit additional;
- SPH - average speed per unit of load;
- RP - average rate per unit of load;
- $H1$ - hours for unit of load per unit of load;
- $T3$ - thickness of material per unit of load;
- $T3$ - average speed per unit of load.

File # 10, No. 1
REF 10, No. 1

Panel Fit and Trim - Footage

$$H_i = \text{SPI} \cdot \text{RP} \cdot \text{HT} \cdot \text{IT}$$

where

- H_i = hours for panel fit and trim
- SPI = average footage length
- RP = Average Rate Transformer
- HT = hours per foot for fit and trim
(differing from set surface value)

Assembly and Assembly - Average Surface Area

$$H_i = 2 \left[\text{RP} \cdot \text{RN} \cdot \text{Q} \cdot \text{SPI} \cdot \text{SN} \cdot \text{SQ} \cdot \text{HI} \right]$$

where

- H_i = hours for assembly, trim and layout
- R = size scaling constant
- HI = assembly hours per unit length for clamp and layout

Note - Definition of terms between parentheses in the above equation are indicated in the following terms: RN, SN, SPI, and RP given for the facility, the number in that order is the scaling factor indicated above.

Panel Detailing and Sectioning

$$H_i = \text{RP} \cdot \text{RN} \cdot \text{Q} \cdot \text{SPI} \cdot \text{SN} \cdot \text{SQ} \cdot \text{HI} \cdot \text{IT}$$

where

- H_i = hours for panel detailing and sectioning
- IT = hours per foot for fitting

Finish (hours) = $\frac{H_1}{2} \left[\frac{R}{R+Q} \left(\frac{Q}{R+Q} \right)^2 + \frac{R}{R+Q} \left(\frac{R}{R+Q} \right)^2 \right] \left(\frac{H_1}{H_1} \right)$

where

H_1 = hours for fastener installation

R = hours per unit length of fastener

Q = factor for fastener selection

Fastener selection = $\frac{H_1}{2} \left[\frac{R}{R+Q} \left(\frac{Q}{R+Q} \right)^2 + \frac{R}{R+Q} \left(\frac{R}{R+Q} \right)^2 \right] \left(\frac{H_1}{H_1} \right)$

where

H_1 = hours for fastener installation

R = hours per foot for fastener installation

Q = factor for fastener selection

Fastener selection = $\frac{H_1}{2} \left[\frac{R}{R+Q} \left(\frac{Q}{R+Q} \right)^2 + \frac{R}{R+Q} \left(\frac{R}{R+Q} \right)^2 \right] \left(\frac{H_1}{H_1} \right)$

Fastener selection = $\frac{H_1}{2} \left[\frac{R}{R+Q} \left(\frac{Q}{R+Q} \right)^2 + \frac{R}{R+Q} \left(\frac{R}{R+Q} \right)^2 \right] \left(\frac{H_1}{H_1} \right)$

Assembly (hr)

$$H_1 = \left[\frac{WRRP}{H_1} + \frac{CSL}{H_1} + \frac{FSL}{H_1} + \frac{FRL}{H_1} + \frac{RSL}{H_1} + \frac{WR}{H_1} \right] \left(\frac{H_1}{H_1} \right)$$

where

H_1 = component material selection factor for material selection

$WRRP$ = root of length in foot

CSL = center section of fastener length in foot

FSL = front spar length in foot

FRL = front spar length in foot

RSL = rear spar length in foot

WR = size selection factor

$\frac{1}{N} \sum_{i=1}^N \frac{1}{H_i} = \frac{1}{N} \sum_{i=1}^N \frac{1}{H_i} = \frac{1}{N} \sum_{i=1}^N \frac{1}{H_i}$

T_1 = paint thickness, in. $T_1 = .04$
 T_2 = average skin thickness
 F_1 = factor for skin type 1
 H_1 = cost per unit paint for assembly
 CMP_1 = cost per unit paint for assembly

Paint and Finish

$$H_1 = ASU_1 \cdot HS_1$$

where

H_1 = hours for paint and finish
 ASU_1 = surface area, m^2
 HS_1 = hours per square foot for paint and finish

Assembly Line

$$H_1 = CMP_1 \cdot RPP_1 \cdot W_1$$

where

H_1 = total painting assembly hours for 100 units, including surface area
 CMP_1 = cost per unit paint for assembly
 RPP_1 = ratio of paint to surface area
 W_1 = total weight of the unit, including the container, for 100
 F_1 = factor for skin type 1

Paint and Finish

Paint and finish cost for 100 units

$\hat{M}_i = \frac{1}{n} \sum_{j=1}^n \hat{M}_{ij}$
 $\hat{W}_i = \frac{1}{n} \sum_{j=1}^n \hat{W}_{ij}$
 $\hat{G}_i = \frac{1}{n} \sum_{j=1}^n \hat{G}_{ij}$
 $\hat{RM}_i = \frac{1}{n} \sum_{j=1}^n \hat{RM}_{ij}$
 $\hat{SI}_i = \frac{1}{n} \sum_{j=1}^n \hat{SI}_{ij}$

where

- \hat{M}_{ij} material and processing cost of the i th component in the j th lot
- \hat{W}_{ij} a series of weightings representing the frequency of spare, repair, and other maintenance activities
- \hat{G}_{ij} a series of weightings representing the frequency of maintenance activities
- \hat{RM}_{ij} a series of weightings representing the frequency of maintenance activities
- \hat{SI}_{ij} a series of weightings representing the frequency of maintenance activities

where

$$\hat{M}_{ij} = \frac{1}{n} \sum_{k=1}^n \hat{M}_{ijk}$$

where

- \hat{M}_{ijk} material and processing cost of the i th component in the j th lot
- \hat{W}_{ijk} a series of weightings representing the frequency of spare, repair, and other maintenance activities
- \hat{G}_{ijk} a series of weightings representing the frequency of maintenance activities
- \hat{RM}_{ijk} a series of weightings representing the frequency of maintenance activities
- \hat{SI}_{ijk} a series of weightings representing the frequency of maintenance activities

The first part of the paper is devoted to the study of the properties of the function $f(x)$ defined by the equation $f(x) = \sum_{n=0}^{\infty} a_n x^n$, where $a_n = \frac{1}{n!}$. It is shown that $f(x)$ is an entire function and that $f(x) = e^x$. The second part of the paper is devoted to the study of the properties of the function $g(x)$ defined by the equation $g(x) = \sum_{n=0}^{\infty} b_n x^n$, where $b_n = \frac{1}{n!}$. It is shown that $g(x)$ is an entire function and that $g(x) = e^x$. The third part of the paper is devoted to the study of the properties of the function $h(x)$ defined by the equation $h(x) = \sum_{n=0}^{\infty} c_n x^n$, where $c_n = \frac{1}{n!}$. It is shown that $h(x)$ is an entire function and that $h(x) = e^x$.

RECURRING PRODUCTION COSTS

Eq. (22) Eq. (23)

REF. 1

CDP

2 Rework, Primary Assembly and Major Mate

NONRECURRING DESIGN AND DEVELOPMENT

1 Basic Structure Design Engineering Hours

$$BEP_1 = PH_1 WAMPR_1 F1$$

where

PH_1 = Design Engineering Hours

PH_1 = Empirical estimate coefficient for structural component

$WAMPR_1$ = ADPP weight of the structural component in the estimate

$F1$ = Scaling exponent of engineering hours to weight

and value of Design Engineering Hours

$$CDP_1 = PH_1 F1$$

where

CDP_1 = Composite Design Engineering Hours

$F1$ = Factor for composite design engineering hours

Factor for Material

$$EMD_1 = PH_1 F1$$

where

EMD_1 = Engineering data for Material Cost

$F2$ = A Percentage Factor Applied to configuration design engineering hours

DEFINITIONS

Definition: Previously used percentage factors applied to the totals obtained from the application of equation (22).

Definition: Base structure design engineering hours, so the detail is a sum of the elements of the structure, such as supporting activities as time and effort in base, stress, weights, and value engineering as they relate to the element of basic structure.

Definition: Composite design engineering hours, so the support activities are a sum of the elements of the structure, such as supporting activities as time and effort in base, stress, weights, and value engineering as they relate to the element of basic structure.

Definition: The value engineering data, so the support activities are a sum of the elements of the structure, such as supporting activities as time and effort in base, stress, weights, and value engineering as they relate to the element of basic structure.

FIG. 21
REF. 2

Eq. No.
Col. B

4

Basic Tool Manufacturing Hours

$$BTMH_i = TMF_i \cdot WAMPR_i^{ET}$$

where

$BTMH_i$ = Basic tool manufacturing hours

TMF_i = Empirical estimating coefficient by structural component

ET = Scaling exponent, tool manufacturing hours to weight

DEFINITIONS

Definition: Basic tool manufacturing hours are those required to produce a complete set of tools adequate to accomplish the manufacturing process. It is assumed that this set of tools will be capable of supporting a production rate of from one to three units per month.

5

Rate Tool Manufacturing Hours

$$RTMH = \left(\sum BTMH_i \right) (FAM - 1)$$

where

$\sum BTMH_i$ = (619, 7) SAV Matrix summation

$RTMH$ = Rate tool manufacturing hours

FAM = Monthly production rate

ER = Exponent for scaling of rate tooling to production rate

Definition: Rate tooling is the tool provisioning required to increase production capability to a required rate.

6

Basic Tool Engineering Hours

$$BTEH = \left(\sum BTMH_i \right) F3$$

where

$BTEH$ = Basic tool engineering hours

$F3$ = Decimal percentage: ratio of basic tool engineering to basic tool manufacturing hours.

Definition: The tool design and production engineering and planning required for the initial production set-up. This would typically be associated with flight test airframe quantities.

FIG. 21 REF.	EQ. NO. VOL. II	CER		DEFINITIONS
7		Rate Tool Engineering Hours		Definition: Tool design and production engineering and planning required for increase to required production rate.
	32	$RTEH = RTMH \cdot F4$		
		where		
		$RTEH =$ Rate tool engineering hours		
		$F4 =$ Decimal percentage: ratio of rate tool engineering hours to rate tool manufacturing hours.		
		Manufacturing Development and Plant Engineering Hours		Definition: Support to the manufacturing process by developing new techniques and processes and providing plant rearrangement.
	34	$MDPEL = TTMH \cdot F5$		
		where		
		$MDPEH =$ Manufacturing Development and Plant Engineering Hours		
		$F5 =$ Decimal percentage: ratio of MDPEH to total tool manufacturing hours.		
9		Tooling Material and Other Dollar Costs		Definition: Procurement of materials to support tool design and manufacture and the manufacturing support activities.
	36	$TMOD = TTMH \cdot F6$		
		where		
		$TMOD =$ Tooling material and other dollar costs		
		$F6 =$ Per hour allowance for tooling material and other costs (\$/hr)		
10		Manufacturing Support Dollar Costs		Definition: Vendor associated start-up costs and manufacturing activities in support of engineering design.
	37	$MSD = CDED \cdot F7$		
		where		
		$MSD =$ Manufacturing support dollars		
		$F7 =$ Decimal percentage: ratio of MSD to configuration design engineering dollars		

CONCLUSION

Definition: Inspection and quality control activities used by management and government to establish quality control procedures and inspection requirements.

Figure 1

Figure 1 shows a series of 10 small diagrams illustrating the process of a person's movement. The diagrams are arranged in a vertical column. Each diagram shows a person's head, shoulders, and arms in a different position, representing a sequence of movements. The person is shown from the side, with their head tilted back and arms raised in some diagrams, and more upright in others. The diagrams are labeled with numbers 1 through 10, indicating the order of the movements.

$$1.63 \cdot 10^{11} \text{ B} \cdot \text{cm}^{-2} \cdot \text{H}(\text{H})$$

white

14. (2014) 2014年12月10日

Decimal fraction: ratio of QCH to configuration design engineering

Fig. 9. Decimal fraction, ratio of α/β to total tool manufacturing hours.

Figure 1 consists of 15 small, vertically arranged line drawings illustrating the stages of chick development. The drawings are numbered 1 through 15. Stage 1 shows a single cell. Stage 2 shows a two-cell embryo. Stage 3 shows a four-cell embryo. Stage 4 shows a morula. Stage 5 shows a blastula. Stage 6 shows a gastrula. Stage 7 shows a neurula. Stage 8 shows a stage with a visible head. Stage 9 shows a stage with a visible tail. Stage 10 shows a stage with a visible beak. Stage 11 shows a stage with a visible leg. Stage 12 shows a stage with a visible wing. Stage 13 shows a stage with a visible eye. Stage 14 shows a stage with a visible ear. Stage 15 shows a fully formed chick with a beak and legs.

Sustaining Engineering Excellence

$$\text{SEH} = (\text{DEH} \cdot \text{GDEH}) / \text{DN2} \quad -1.0$$

where

SEI Sustaining engineering hours

DEH and (DEH) p.m. See Equations (23) and (25)

PN2 RDTE number of units

Samuel Johnson, *Dictionary of the English Language*

$$STH = \frac{(TTM + TIER + MDPH) (PN_2 - 1)}{0.14} \quad (41)$$

where

Will Sustaining Tooling hours

TTMH = Total tool manufacturing hours

THREE - Total tool changeover hours

Mfg. development and plant engineering hours

Definition: The engineering task can be done with the production effort. An allowance for engineering support is given and above a specific definition of this.

Definition The task of maintaining tooling and production planning to support the production effort.

Table 21	Eq. No.	CLR
REF.	Vol. II	
		Manufacturing Summary:
		Detail Fabrication Labor
		Subassembly and Assembly Labor
		Material Costs
4		Cost estimated = $p_1 \sum_{i=1}^x$
		where
		p_1 = First unit cost
		p_2 = The number of RDTech units
		x = $\frac{\ln p_2}{\ln 2}$ where
		p_3 = The relevant learning curve factor expressed as a decimal fraction.
4		Primary Assembly and Major Mate. Hours
		$MMH = [632.7 - 633.7] \quad MMPC \times 10$
		where
		$MMPC$ = Percentage factor
		Quantity Control Hours
44		$QCH = [632.7 - 633.7] \times 10$
4		Primary Assembly and Major Mate. Material
		$MMV = 636.8 \times MMH$
		where
		636.8 = Summation of material costs for structural elements
		MMH = Major mate. assembly percentage factor

DEFINITIONS

Definition: First unit costs for detail fabrication, subassembly and assembly combined, and production material costs summarized and projected over the quantity indicated using an aggregate learning curve value.

Definition: A summarization of primary assembly and major mate hours based on previously used percentage factor

Definition: Previously used percentage factor applied to a summarization of detail fabrication, subassembly, assembly, primary assembly and major mate hours.

Definition: Production material used in primary assembly and major mate, estimated as a percentage of structural material.

APPENDIX B

CERs FOR SYSTEM STUDY COST ESTIMATING METHOD

The cost estimating relationships described below comprise the system study cost estimating method for the airframe, including functional subsystems. CERs are shown for nonrecurring, first unit, and recurring costs.

Nonrecurring Design and Development Costs

ENGINEERING:

BASIC STRUCTURE DESIGN ENGINEERING

$$DE_i = F_i (EC_i) (WE_i)^{E_i} \quad (1)$$

where

DE_i = Design engineering hours for each structural element estimated

F_i = Complexity factor

EC_i = Estimating coefficient

WE_i = Weight of the structural element estimated

E_i = Cost/weight scaling exponent

i = Index numbers, 1 through 6 for basic structure

CONFIGURATION DESIGN ENGINEERING

$$CDE = F7 (EC) (WAMP)^{E2} \quad (2)$$

where

CDE = Configuration design engineering hours

F7 = Complexity factor

EC = Estimating coefficient = 1840

WAMP = AMPR weight of the total basic structure

E2 = Cost/weight scaling exponent

EQUIPMENT DESIGN ENGINEERING

$$EDE_i = F_i (EC_i) (WE_i) E_i \quad (3)$$

where

EDE_i = Equipment design engineering hours for each functional subsystem
and F_i , EC_i , WE_i and E_i are as defined before. The index, i , runs from 8 through 18 inclusive, corresponding to the functional subsystems as listed in Figure 39.

TOTAL ENGINEERING LABOR

Total engineering labor is the summation of the previous estimates accomplished by an R-card, line 722. The formula appears as follows:

$$TEL = \sum (701 \dots 718, 1) \quad (4)$$

where

TEL = Total engineering labor,

and the summation is of the series of estimates recorded in the SAV matrix from line 701 through 721.

ENGINEERING DOLLAR COSTS

$$EDC = TEL (ECLR1) \quad (5)$$

where

EDC = Engineering dollar costs

ECLR1 = Composite engineering labor rate

ENGINEERING MATERIAL COSTS

$$EM = EDC (FM) \quad (6)$$

where

EM = Engineering Material cost

EDC = Engineering dollar cost taken from the SAV matrix at (723, 2)

FM = A percentage factor

TOTAL LABOR AND MATERIAL COST

$$TLM = EDC + FM \quad (7)$$

TOOLING:

BASIC TOOL MANUFACTURING HOURS

$$BT_i = TF_i (EC_i) (WE_i)^{T_i} \quad (8)$$

where

BT_i = Basic tool manufacturing hours by hardware element

TF_i = Complexity factor for tooling

EC_i = Estimating coefficient

WE_i = Weight of the structural element estimated

T_i = Cost/weight scaling exponent

i - Index numbers 1 through 7 for tooling elements

RATE TOOL MANUFACTURING HOURS

$$RT_i = BT_i (R^{TR} - 1) \quad (9)$$

where

RT_i = Rate tool manufacturing hours by hardware element

R = Production rate

TR = Scaling with production rate increase

TOTAL TOOL MANUFACTURING

Basic and Rate Tool Manufacturing Hours are summed by column for each hardware element, for other subsystems and for the subtotals.

BASIC TOOL ENGINEERING

$$BTEH_i = BT_i (TEF_i) \quad (10)$$

$BTEH_i$ = Basic tool engineering hours by hardware element

TEF_i = Tool engineering factor: a ratio of tool engineering to tool manufacturing

RATE TOOL ENGINEERING HOURS

$$RTEH_i = RT_i (RTEF_i) \quad (11)$$

where

$RTEH_i$ = Rate tool engineering hours by hardware element

$RTEF_i$ = Rate tool engineering factor

TOTAL TOOL ENGINEERING

Basic and Rate Tool Engineering Hours are summed in the same way as Tool Manufacturing.

TOOL MATERIAL COST

$$TM = TTM (TMF2) \quad (12)$$

where

TM = Tooling material cost

TTM = Total tool manufacturing hours

TMF2 = Tooling material factor: a ratio of tooling material to tool manufacturing

MANUFACTURING AIDS COSTS

$$MAH = TTM (MAF) \quad (13)$$

where

MAH = Manufacturing aids hours

MAF = Manufacturing aids factor

MANUFACTURING DEVELOPMENT COSTS

$$MDH = TTM (MDF) \quad (14)$$

where

MDH = Manufacturing development hours

MDF = Manufacturing development factor

MANUFACTURING SUPPORT:

$$MS = 0.008325 (WAMP)^{.873} (S)^{1.89} (QD)^{.346} (INF) \quad (15)$$

where

MS = Manufacturing support cost in 1974 dollars

S = Maximum speed (kts) at best altitude

QD = Development quantity (number of flight test airframes)

INF = A term to adjust the dollar base from 1970 to 1974 as follows:

$$INF = 1.273 \times (1 + RI)^{(Y - 1974)} \quad \text{and}$$

RI = Rate of inflation

Y = Year in which dollars are stated

QUALITY CONTROL

$$QCH = TEL (QCF1) + TTM (QCF2) \quad (16)$$

where

QCH = Quality control hours

QCF1 = Factor applied to engineering labor

QCF2 = Factor applied to tool manufacturing labor

First Unit Costs

BASIC STRUCTURE FIRST UNIT COSTS

$$CFU_i = UF_i (EC_i) (WE_i)^{E_i} (INF) + (SAV_i) \quad (17)$$

where

CFU_i = Cost of the first unit of the element estimated

UF_i = Complexity factor

WE_i = Weight of the structural element being estimated

E_i = Cost/weight scaling exponent

INF = Adjustment of 1970 data base to 1974 base as shown in Equation (15)

SAV_i = SAV matrix

SUBSYSTEMS FIRST UNIT COSTS

Same as above except the term (SAV_i) is omitted.

Recurring Production Costs

These cost items consist of the following:

Sustaining Engineering

Sustaining Tooling

Manufacturing (Including Quality Control) for:

Wing

Horizontal Stabilizer

Vertical Stabilizer

Fuselage

Nacelles

Landing Gear

Subsystems

SUSTAINING ENGINEERING HOURS

$$SEH = TEL (QN2^{ES} - 1) \quad (18)$$

where

SEH = Sustaining engineering hours

TEL = Total engineering labor

QN2 = RDT&E quantity

ES = Scaling against quantity

The equation used for procurement quantities is

$$SEH = TEL (QN4^{ES} - QN2^{ES}), \quad (19)$$

or $(QN6^{ES} - QN2^{ES})$ for the second procurement quantity, where

$$QN4 = QN2 + QN3$$

$$QN6 = QN2 + QN5$$

SUSTAINING TOOLING HOURS

$$STH = (TTM + TTE) (QN2^{TU} - 1) \quad (20)$$

where

STH = Sustaining tooling hours

TTM = Total tool manufacturing hours

TTE = Total tool engineering hours

TU = Scaling against quantity

The equation used for procurement quantities is

$$STH = (TTM + TTE) (QN4^{TU} - QN2^{TU}), \quad (21)$$

or $(QN6^{TU} - QN2^{TU})$ for the second procurement quantity.

MANUFACTURING RECURRING COSTS

Based on first unit manufacturing costs, recurring manufacturing costs are projected on a dollar basis. Exactly the same procedure is used as was used for the trade study recurring production costs by structural element. A Z-card calculation based on TERM 29 is used. This has the equational form,

$$\text{Cost Estimated} = P1 \sum_{P2}^{P3} i^x \quad (22)$$

with the same definitions as in Section 2.2.4.2. The calculation is performed for each of the aircraft subsystems.

Quality Control costs are included in the first unit cost estimate.

APPENDIX C

COSTC PROGRAM SOURCE DECK LISTING

This appendix provides a program source deck list for the COSTC data manager program.

```

C COSTC (INPUT, TAPE 1; INPUT, COSTC
1 OUTPUT, TAPE 2; OUTPUT, COSTC
2 TAPE 3; COSTC
3 TAPE 4; COSTC
4 TAPE 5) COSTC
5 COSTC
6 DE REALIZED COST MODEL COSTC
7 COSTC
8 COSTC
9 COSTC
10 COSTC
11 COSTC
12 COSTC
13 COSTC
14 COSTC
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100 COSTC

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[illegible]

45	FORWARD(101)	COSTC
	IF (CASE .EQ. 1) GO TO 50	COSTC
	IF (CASE .EQ. 2) GO TO 100	COSTC
50	TAPE=1	COSTC
	CALL F04(10,000,2100)	COSTC
		COSTC
100	CALL F000	COSTC
		COSTC
110	FORWARD(3010)	COSTC
		COSTC
	GO TO (310,320,330),I=0	COSTC
	CARDS	COSTC
310	CONTINUE	COSTC
	READ TAPE1 DATA OF MODEL FROM CARDS TO TAPE INHIT.	COSTC
	IF = 0	COSTC
311	CONTINUE	COSTC
	READ(11,110) (TEMP(I),I=1,8)	COSTC
	IF (END(11)) 312,315	
312	CONTINUE	COSTC
	WRITE(5,313)	COSTC
313	FORMAT(7777 4SH FOR M1T OF MODEL CARDS. NO 2-CARD. CHECK INPUT.)	COSTC
	STOP	COSTC
315	CONTINUE	COSTC
	WRITE(10011,110) (TEMP(I),I=1,8)	COSTC
	RECODE(1,010,TEMP)KEY	COSTC
	IF (KEY .NE. 1HE) GO TO 311	COSTC
	REWIND TAPE1	COSTC
	IF (102 .EQ. 305) GO TO 331	COSTC
	GO TO 300	COSTC
	TAPE=2	COSTC
320	CONTINUE	COSTC
	IF (CASE .EQ. 1) GO TO 321	COSTC
	INPUT DATA OF MODEL IS ALREADY ON TAPE INHIT. REWIND TAPE.	COSTC
	REWIND TAPE1	COSTC
	GO TO 300	COSTC
321	CONTINUE	COSTC
	INPUT DATA OF MODEL FROM TAPE2 TO TAPE INHIT.	COSTC
	IF = 2	COSTC
	GO TO 311	COSTC
	IF (CASE = 1, WRITE TAPE2 ONTO TAPE3 AND MERGE ONTO TAPE4.	COSTC
	WRITE TAPE4 ONTO TAPE3.	COSTC
	OTHERWISE JUST MERGE CARDS WITH TAPE3 ONTO TAPE4 AND WRITE	COSTC
	TAPE4 ONTO TAPE3.	COSTC
330	CONTINUE	COSTC
	TEST. IS THIS THE FIRST CASE.	COSTC
	IF (CASE .EQ. 1) GO TO 335	COSTC
331	CONTINUE	COSTC
	102 = 0	COSTC
	MERGE CARDS FROM TAPE3 WITH INPUT ON TAPE INHIT TO TAPE 11.	COSTC
	IF = 4	COSTC
	CALL MERGE(INHIT,11)	COSTC
	GO TO 311	COSTC
335	CONTINUE	COSTC
	FIRST TIME. TAPE2 TO INHIT. MERGE TO 11. THEN 11 TO INHIT.	COSTC
	102 = 305	COSTC
	IF = 2	COSTC
	GO TO 311	COSTC
		COSTC
	THE MODEL LOOP STARTS HERE	COSTC

LOOP6=2	COSTC
LOOP6=7	COSTC
CALL COTPAR	COSTC
RECODE (10,610,TEMP)KEY,LINE	COSTC
CALL RECORD(LINE)	COSTC
MARRAY1=MARRAY(1)	COSTC
DO 265 I=2,6	COSTC
IF (MARRAY(I).EQ.0) GO TO 270	COSTC
MARRAY1=MARRAY(I)	COSTC
SAV(LINE,MARRAY1)=SAV(LINE,MARRAY1)*COFF(I-1)	COSTC
265 CONTINUE	
270 CONTINUE	COSTC
DO 261 I=1,IADD	COSTC
IADJAY1=IADJAY(I,1)	COSTC
DO 262 J=2,7	COSTC
IADJAYJ=IADJAY(I,J)	COSTC
IF (IADJAYJ.EQ.0) GO TO 261	COSTC
SAV(LINE,IADJAY1)=SAV(LINE,IADJAY1)+SAV(LINE,IADJAYJ)	COSTC
262 CONTINUE	COSTC
261 CONTINUE	COSTC
GO TO 360	COSTC
C	COSTC
400 CONTINUE	COSTC
DO 470 J=1,ICOL	COSTC
SAV(LINE,13)=SAV(LINE,13) + SAV(LINE,J)	COSTC
670 CONTINUE	COSTC
ENCODE(CHAR,FMT,TEMP2) (SAV(LINE,I),I=1,ICOL)	
IF (ICPR.EQ.0) GO TO 470	COSTC
ENCODE(10,420,TEMP2(ICPR)) SAV(LINE,13)	COSTC
420 FORCAT(12(3X,F7.2))	COSTC
IF (SAV(LINE,13).EQ.0.) TEMP2(ICPR)=BLANK	COSTC
425 DO 430 I=1,ICOL	COSTC
IF (SAV(LINE,I).EQ.0.) TEMP2(I)=BLANK	COSTC
430 CONTINUE	COSTC
RECODE(2,440,TEMP) IDENT	COSTC
440 FORCAT(1X,A1)	COSTC
IF (IDENT.EQ.1H1) GO TO 460	COSTC
WRITE (6,450) (TEMP(I),I=1,4),(TEMP2(I),I=1,ICPR)	COSTC
450 FORCAT(3X,R7,2A10,A8,12(R7,1X))	COSTC
GO TO 360	COSTC
460 WRITE (6,470) (TEMP(I),I=1,4),(TEMP2(I),I=1,ICPR)	COSTC
470 FORCAT(3X,R7,3A10,12(R7,1X))	COSTC
GO TO 360	COSTC
C	COSTC
500 CONTINUE	COSTC
RECODE(10,610,TEMP) KEY,LINE,ICOL,ITERM	COSTC
CALL RECORD(LINE)	COSTC
LOOP6=2	COSTC
LOOP6=5	COSTC
C	COSTC
CHECK IF THERE ARE CONTINUATION CARDS	COSTC
CALL CHECK(1,UNIT,TEMP2,KFLAG)	COSTC
IF (KFLAG.EQ.0) GO TO 550	COSTC
DO 530 I=2,6	COSTC
TEMP(7+I)=TEMP2(I)	COSTC
530 CONTINUE	COSTC
LOOP6=15	COSTC
550 CONTINUE	COSTC
IF (KEY.EQ.1H1) GO TO 1500	COSTC
SAV(LINE,ICOL)=SAV(LINE,ICOL) + TERM(ITERM)	COSTC
GO TO 360	COSTC

C		COSTC
600	CONTINUE	COSTC
	RECDE(13,010,TEMP) KEY,LINE,ICOL,ICOL,ITERM	COSTC
	CALL RECORD(LINE)	COSTC
610	FOR=41(81,413)	COSTC
	LOC=13	COSTC
	LOC=1	COSTC
C	CHECK IF THERE ARE CONTINUATION CARDS	COSTC
	CALL CHECK(THROW1,TEMP2,KFLAG)	COSTC
	IF(KFLAG .NE. 0) GO TO 650	COSTC
	LOC=1+2*8	COSTC
	TEMP(7+1)=TEMP2(1)	COSTC
630	CONTINUE	COSTC
	LOC=13	COSTC
640	CONTINUE	COSTC
	IF=1	COSTC
	IF=600 ICOL=ICOL,ICOL	COSTC
	IF=1	COSTC
	SAVE(LINE,ICOL)=SAVE(LINE,ICOL) + TERM(ITERM)	COSTC
660	CONTINUE	COSTC
	IF=1	COSTC
	GO TO 600	COSTC
C		COSTC
700	CONTINUE	COSTC
	WRITE(6,45)	COSTC
	GO TO 300	COSTC
C		COSTC
750	CONTINUE	COSTC
	WRITE(6,710) (TEMP(I),I=1,8)	COSTC
710	FOR=41(1X,6X,7A10)	COSTC
	GO TO 300	COSTC
C		COSTC
800	CONTINUE	COSTC
	CALL TITLE	COSTC
	GO TO 300	COSTC
C		COSTC
900	CONTINUE	COSTC
	RECDE(80,910,TEMP) NCOL,ITSOP, TITLE	COSTC
910	FOR=41(1X,12A1,6X,7A10)	COSTC
	NCOL=ICOL*10	COSTC
	NCPR=NCOL	COSTC
	IF(1150P .NE. 10 .AND. NCOL .LT. 12) NCPR=NCOL+1	COSTC
	GO TO 300	COSTC
C		COSTC
1000	CONTINUE	COSTC
	RECDE(80,1010,TEMP) (ICOL(I,1),I=1,13)	COSTC
1010	FOR=41(10X,13A5)	COSTC
	IFROW=1	COSTC
	GO TO 300	COSTC
1020	CONTINUE	COSTC
	RECDE(80,1010,TEMP) (ICOL(I,2),I=1,13)	COSTC
	IFROW=2	COSTC
	GO TO 300	COSTC
1030	CONTINUE	COSTC
	RECDE(80,1010,TEMP) (ICOL(I,3),I=1,13)	COSTC
	IFROW=3	COSTC
	GO TO 300	COSTC
C		COSTC
1100	CONTINUE	COSTC
	WRITE(6,45)	COSTC

```

      WRITE (6,1102) (LLIST(I),I=1,JW0)
1102 FORK=1(200*LLIST(JTS/(100,10A10))
      DO 1103 I=1,IW0
      DO 1103 J=1,JW0
      ISUB=(J-1)*JW0+1
1103 TEMP2(J)=PL(ISUB)
      WRITE (6,1104) LLIST(I),(TEMP2(J),J=1,JW0)
1104 FORK=1(2*JW0,10L10,2)
1105 CONTINUE
      WRITE (6,45)
      WRITE (6,1106)
1106 FORK(1106,SAV MATRIX)
      LNC=0
      DO 1120 LN=1,LINE
      IF (10*KLIN(LN),LN,0) GO TO 1120
      WRITE (6,1111) LN,(SAV(LN,I),I=1,15)
1111 FORK=1(15,15L10,2)
      LNC=LNC+1
      IF (805(LNC,55),LNC,0) WRITE (6,45)
1120 CONTINUE
      GO TO 300
C
1200 CONTINUE
      KEY = KEY
      KEY=102
      LOOPS=2
      LOUPL=7
      DO 1205 I = 2,7
      IF (TEMP(I) .EQ. BLANK) TEMP(I) = ZERO
1205 CONTINUE
      CALL CHECK(100011,TEMP2,KFLAG)
      IF (KFLAG.EQ.0) GO TO 1220
      DO 1210 I=2,7
      TEMP(I+1)=TEMP2(I)
      IF (TEMP(I+6) .EQ. BLANK) TEMP(I+6) = ZERO
1210 CONTINUE
      LOUPL = 15
1220 CONTINUE
      CALL GETPAR
      DECODE(100010,TEMP) KEY, LINE
      CALL RECORD(LINE)
      KEYS = 0
      ISIP = LOUPL - 1
      DO 1230 I = 1,ISIP
      SAV(LINE,I)=PRF(SIP(I))
1230 CONTINUE
      GO TO 300
1300 CONTINUE
      DECODE(100010,TEMP) KEY, LINE, ICOL, MARRAY(1)
      DO 1310 I=2,6
      DECODE(10,1520,TEMP(I))(PARAM(J),J=1,10)
      CALL FINDIN(PARAM,MARRAY(I))
1320 FORK(10A1)
1310 CONTINUE
      GO TO 300
1410 CONTINUE
      IADD=IADD+1
      DECODE(100010,TEMP) KEY, LINE, ICOL, IADDAY(IADD,1)
      DO 1420 I=2,6
      DECODE(10,1520,TEMP(I))(PARAM(J),J=1,10)

```

[illegible]

	IF (JSTEP .EQ. 3) IP=1	
	GO TO 500 IF IP=15187, LOOPE	
C		GETPAR
	FIELD=100*(IEMP)	GETPAR
	RECV=100*(FIELD) (CHAR(I), I=1, 10)	GETPAR
110	CONT=100*(10A1)	GETPAR
	DO 120 I=1, 10	GETPAR
	IF (CHAR(I) .EQ. BLANK) GO TO 140	GETPAR
120	CONT=RE	GETPAR
C	FIELD IS BLANK	GETPAR
	GO TO 300	GETPAR
C		GETPAR
140	CONTINUE	
	IF (JSTEP .EQ. 24 .OR. JSTEP .EQ. 29) GO TO 145	
	CALL SEARCH(DIGIT, 13, CHAR(I), I=1)	
	IF (IND .GT. 0) GO TO 200	GETPAR
C	NOT BE A WEIGHT NAME	GETPAR
145	NAME=RWORL(CHAR, 1, 6)	
	NAME=RWORL(CHAR, 7, 10)	GETPAR
	IF (KEY .EQ. 1H2) GO TO 180	GETPAR
C	GET WEIGHT AND ELEMENTS FROM ALL R-CARD	GETPAR
	CALL SEARCH(WLIST, IND, WANT, IND)	GETPAR
	IF (IND .EQ. 0) GO TO 160	GETPAR
	IND=IND+1	GETPAR
	WLIST(IND)=IND	GETPAR
	GO TO 160	GETPAR
160	CALL SEARCH(ELIST, JWD, WANT, IND)	GETPAR
	IF (IND .EQ. 0) GO TO 182	GETPAR
	IND=IND+1	GETPAR
	ELIST(IND)=IND	GETPAR
164	CALL SEARCH(ELIST, JWD, ENAME, IND)	GETPAR
	IF (IND .EQ. 0) GO TO 300	GETPAR
	IND=IND+1	GETPAR
	ELIST(IND)=IND	GETPAR
	GO TO 300	GETPAR
C		GETPAR
180	CALL SEARCH(WLIST, IND, WANT, KW)	GETPAR
	CALL SEARCH(ELIST, JWD, ENAME, KE)	GETPAR
	IF (KW*KE .GT. 0) GO TO 190	GETPAR
C		GETPAR
C	UNABLE TO MATCH WEIGHT OR ELE - SET TO 1.0	GETPAR
C		GETPAR
182	WRITE(6, 184) WANT, ENAME	GETPAR
184	FORMAT(*0 UNABLE TO MATCH *, A6, 2X, A4, * IN WEIGHT OR ELEMENT LIST, *SET PARAMETER TO 1.0 AND CONTINUE,*)	GETPAR
	IP=IP+1	GETPAR
	PARAM(IP)=1.0	GETPAR
	GO TO 300	GETPAR
190	ISUB= (KE-1)*AXX+KW	GETPAR
	WORD=PL(ISUB)	GETPAR
	IF (KEY .EQ. 1H5) GO TO 265	GETPAR
	IP=IP+1	GETPAR
	PARAM(IP)=WORD	GETPAR
	GO TO 300	GETPAR
C	SEARCH FOR DECIMAL POINT	GETPAR
200	DO 210 I=1, 10	GETPAR
	IF (CHAR(I) .EQ. DIGIT(11)) GO TO 400	GETPAR
210	CONTINUE	GETPAR
C	IT MUST BE AN INTEGER FIELD	GETPAR
C	JO COUNTS THE NUMBER OF INTEGERS	GETPAR

C	200	GETPAR
C	210	GETPAR
	220	GETPAR
	230	GETPAR
	240	GETPAR
	250	GETPAR
	260	GETPAR
	270	GETPAR
	280	GETPAR
	290	GETPAR
	300	GETPAR
	310	GETPAR
	320	GETPAR
	330	GETPAR
	340	GETPAR
	350	GETPAR
	360	GETPAR
	370	GETPAR
	380	GETPAR
	390	GETPAR
	400	GETPAR
	410	GETPAR
	420	GETPAR
	430	GETPAR
	440	GETPAR
	450	GETPAR
	460	GETPAR
	470	GETPAR
	480	GETPAR
	490	GETPAR
	500	GETPAR
	510	GETPAR
	520	GETPAR
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	770	GETPAR
	780	GETPAR
	790	GETPAR
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	810	GETPAR
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	830	GETPAR
	840	GETPAR
	850	GETPAR
	860	GETPAR
	870	GETPAR
	880	GETPAR
	890	GETPAR
	900	GETPAR
	910	GETPAR
	920	GETPAR
	930	GETPAR
	940	GETPAR
	950	GETPAR
	960	GETPAR
	970	GETPAR
	980	GETPAR
	990	GETPAR
	1000	GETPAR

[illegible][illegible]

	GO TO 10-175	EXPR
	100	EXPR
	IF (IA(I) .EQ. OP(2)) GO TO 20	EXPR
10	CONTINUE	EXPR
	GO TO 40	EXPR
20	CONTINUE	EXPR
	IF (IEC .EQ. 1) GO TO 30	EXPR
	IA(2)=PACK(IA(1),IEC,IEC)	EXPR
	DATA(1)=VALU(IA(2),IEC)	EXPR
30	IF (IEC .EQ. 1) .AND. (IA(I+1) .EQ. OP(2)) L=L+1	EXPR
	IEC=0	EXPR
	IEC(F)=L	EXPR
	K=K+1	EXPR
	IF L=0 L=2	EXPR
	IF (L .EQ. 1) N1=N+1	EXPR
40	CONTINUE	EXPR
	K=N+2	
C		
	GO TO 10-175	
	GO TO 140 10-175	EXPR
	IF (IOPC(2) .EQ. 0) GO TO 140	
	IF (1 .GT. 1) GO TO 60	
	IF (IOPC(2) .EQ. 1) GO TO 140	EXPR
	DATA(2)=DATA(1)*R(UM(J+1))	EXPR
	GO TO 130	
C		
	GO TO 70 L=OPK	
	L=L+1	
	IF (IOPC(1) .GT. 1) GO TO 80	
70	CONTINUE	EXPR
	GO TO 140	
C		
	GO TO (1 .EQ. 3) GO TO 105	
C		
	IF (IOPC(2) = 3) 90,105,140	
90	DATA(4)=DATA(2)+R(UM(I))	
	GO TO 130	EXPR
100	DATA(4)=DATA(2)/R(UM(I))	EXPR
	GO TO 130	EXPR
C		
105	IF (IOPC(2) = 5) 110,120,140	
110	DATA(4)=DATA(2)+R(UM(I))	EXPR
	GO TO 130	EXPR
120	DATA(4)=DATA(2)-R(UM(I))	EXPR
130	IOPC(2) = 6	
140	CONTINUE	EXPR
150	CONTINUE	EXPR
	DATA=DATA(K+1)	
C		
	RETURN	EXPR
999	CONTINUE	EXPR
	RETURN	EXPR
	END	EXPR
	SUBROUTINE CHECK(PUNIT,RECORD,KFLAG)	CHECK
C		CHECK
	THIS ROUTINE CHECKS IF THE NEXT RECORD IN UNIT IS	CHECK
C	A CONTINUATION CARD	CHECK
	DISCUSSION RECORD(F)	CHECK
	KFLAG=0	CHECK
	READ(PUNIT,120) RECORD	CHECK

120	FORMAT(8A10)	CHECK
	DECODE(2,130,RECORD) CONT	CHECK
130	FORMAT(1X,A1)	CHECK
	IF(COUNT.EQ.1HC) GO TO 150	CHECK
	BACKSPACE KUNIT	CHECK
	GO TO 200	CHECK
150	KFLAG=1	CHECK
200	RETURN	CHECK
	END	CHECK
	SUBROUTINE TITLE	TITLE
C		TITLE
C	THIS ROUTINE IS USED TO PRINT THE TITLES	TITLE
	COMMON /PRINTL/ITIM,IDAT,TMAIN(8),TITL(7),	TITLE
	* NCOL,ITSUP,TCOL(13,3),ITROW	TITLE
C		TITLE
	WRITE(6,110) ITIM,IDAT,TMAIN	TITLE
110	FORMAT(/780X,A10,10X,A10/740X,8A10)	TITLE
	WRITE(6,120) TITL	TITLE
120	FORMAT(/ 3X,7A10/)	TITLE
	K=NCOL	TITLE
	IF(ITSUP.NE.1H) K=NCOL+1	TITLE
	DO 140 I=1,ITROW	TITLE
	WRITE(6,130) (TCOL(J,I),J=1,K)	TITLE
130	FORMAT(40X,12(A5,3X))	TITLE
140	CONTINUE	TITLE
	RETURN	TITLE
	END	TITLE
	FUNCTION PWORD(VEC,IB,IE)	PWORD
C	THIS FUNCTION WILL SELECT THE NON-BLANK CHARACTERS	PWORD
C	FROM VEC AND LEFT ADJUST THEM IN PWORD.	PWORD
C		PWORD
	DIMENSION VEC(1),ROWB(10)	PWORD
	DATA BLANK/10H	PWORD
C		PWORD
	PWORD=BLANK	PWORD
	J=0	PWORD
	DO 150 I=IB,IE	PWORD
	IF(VEC(I).EQ.BLANK) GO TO 150	PWORD
	J=J+1	PWORD
	ROWB(J)=VEC(I)	PWORD
150	CONTINUE	PWORD
	IF(J.EQ.0) GO TO 200	PWORD
	ENCODE(J,100,CHARS) (ROWB(I),I=1,J)	PWORD
100	FORMAT(10A1)	PWORD
	PWORD=CHARS	PWORD
200	RETURN	PWORD
	END	PWORD
	FUNCTION NUMBER(IROW,I1,I2)	NUMBER
C	THIS SUBROUTINE GETS AN INTEGER FROM THE IROW VECTOR	NUMBER
C	BETWEEN IROW(I1) AND IROW(I2)	NUMBER
	DIMENSION IROW(1)	NUMBER
C		NUMBER
	NUMBER=0	NUMBER
	LENGTH=I2-I1+1	NUMBER
	IF(LENGTH.LE.0 .OR. LENGTH.GT.8) GO TO 50	NUMBER
C	COMPUTE INTEGER CONTAINED IN FIELD LENGTH	NUMBER
	ENCODE(4,12,MATFOR) LENGTH	NUMBER
12	FORMAT(2H(I,I1,1H))	NUMBER
	ENCODE(LENGTH,20,UNUM) (IROW(I),I=I1,I2)	NUMBER
20	FORMAT(10A1)	NUMBER

DECODE(LENGTH,MATFOR,JNUM) NUM	NUMBER
NUMBER=NUM	NUMBER
RETURN	NUMBER
50 WRITE(5,60)	NUMBER
60 FORMAT(42H0 NUMBER IS TO BIG OR THERE IS AN ARG-ERROR)	NUMBER
STOP	NUMBER
END	NUMBER
LOGICAL FUNCTION MRGCRD(KEYA)	MRGCRD
MRGCRD = .FALSE.	MRGCRD
IF(MRGCRD
1 KEYA .EQ. 1HJ	MRGCRD
2 .OR. KEYA .EQ. 1HK	MRGCRD
3 .OR. KEYA .EQ. 1HH	MRGCRD
4 .OR. KEYA .EQ. 1HR	MRGCRD
5 .OR. KEYA .EQ. 1HZ	MRGCRD
6 .OR. KEYA .EQ. 1HS	MRGCRD
7 .OR. KEYA .EQ. 1HF	MRGCRD
*) MRGCRD = .TRUE.	MRGCRD
RETURN	MRGCRD
END	MRGCRD
SUBROUTINE RECORD(I)	RECORD
COMMON /RECORDP/ ICHK(16)	RECORD
IWORD=(I+49)/50	RECORD
ILOC=1-50*(IWORD-1)	RECORD
J=1	RECORD
CALL SBYT(ILOC,1,ICHK(IWORD),J)	RECORD
RETURN	RECORD
END	RECORD
FUNCTION ICHKLIN(I)	ICHKLIN
COMMON /RECORDP/ ICHK(16)	ICHKLIN
IWORD=(I+49)/50	ICHKLIN
ILOC=1-50*(IWORD-1)	ICHKLIN
ICHLIN=LBYT(ILOC,1,ICHK(IWORD))	ICHKLIN
RETURN	ICHKLIN
END	ICHKLIN
SUBROUTINE FINDINT(TEMP,IND)	FINDINT
DIMENSION TEMP(1)	FINDINT
C THIS SUBROUTINE WILL FIND THE SINGLE INTEGER UP TO 99	FINDINT
C FROM AN INPUT FIELD	FINDINT
C OUTPUT IS LOCATED IN IND	FINDINT
C OUTPUT IS ZERO FOR BLANK INPUT FIELD	FINDINT
DATA BLANK/10H	FINDINT
I1=0	FINDINT
I2=0	FINDINT
DO 10 I=1,10	FINDINT
IF(TEMP(I).EQ.BLANK)GO TO 10	FINDINT
IF(I1.EQ.0)GO TO 15	FINDINT
I2=1	FINDINT
GO TO 20	FINDINT
15 I1=1	FINDINT
10 CONTINUE	FINDINT
IF(I1.EQ.0)GO TO 30	FINDINT
IF(I2.EQ.0)I2=I1	FINDINT
20 IND =NUMBER(TEMP ,I1,I2)	FINDINT
RETURN	FINDINT
30 IND=0	FINDINT
RETURN	FINDINT
END	FINDINT
SUBROUTINE TMERGE(K,M)	TMERGE

C	THIS ROUTINE MERGES THE CARDS WITH THE MODEL ON TAPE2.	TMERGE
C	THE UPDATED MODEL IS WRITEN ON TAPE3.	TMERGE
	DIMENSION CARD(8),REC(8)	TMERGE
	DIMENSION CARD2(8),REC2(8)	TMERGE
	INTEGER C,R,Z	TMERGE
	LOGICAL MRGCRD	TMERGE
	NAMelist /TEST/ ICOLR,LINER,ICOLC,LINEC,LINER,IEND	TMERGE
	1,NOR,NOP,KCFL,KRFL	TMERGE
	DATA C,R,Z/1HC,1HR,1HZ/	TMERGE
C		TMERGE
C	K IS THE TAPE NUMBER FROM WHICH THE MERGE OCCURS.	TMERGE
C	M IS THE TAPE NUMBER ON WHICH THE MERGE OCCURS.	TMERGE
C		TMERGE
	REWIND K	TMERGE
	REWIND M	TMERGE
C		TMERGE
	INSERT=0	TMERGE
	IEND=0	TMERGE
C	READ THE FIRST Z-CARD FROM EACH FILE	TMERGE
100	READ(K,110) REC	TMERGE
110	FORMAT(8A10)	TMERGE
	DECODE(1,150,REC) KEYR	TMERGE
	IF(MRGCRD(KEYR)) GO TO 140	TMERGE
	WRITE(M,110) REC	TMERGE
	GO TO 100	TMERGE
140	DECODE(7,150,REC) KEYR,LINER,ICOLR	TMERGE
150	FORMAT(A1,2I3)	TMERGE
	CALL CHECK(K,REC2,KRFL)	TMERGE
	READ(5,110) CARD	TMERGE
	DECODE(7,150,CARD) KEYC,LINEC,ICOLC	TMERGE
	IF(.NOT. MRGCRD(KEYC)) GO TO 800	TMERGE
C	CHECK IF THERE ARE CONTINUATION CARDS	TMERGE
	CALL CHECK(5,CARD2,KCFL)	TMERGE
C		TMERGE
C	LOOP STARTS HERE	TMERGE
200	IF(LINER-LINEC) 700,250,600	TMERGE
250	IF(ICOLR-ICOLC) 700,300,290	TMERGE
290	INSERT=1	TMERGE
300	WRITE(M,110) CARD	TMERGE
	IF(KCFL .NE. 0) WRITE(M,110) CARD2	TMERGE
	READ(5,110) CARD	TMERGE
	NOP=100*LINEC+ICOLC	TMERGE
	DECODE(7,150,CARD) KEYC,LINEC,ICOLC	TMERGE
	IF(MRGCRD(KEYC)) GO TO 320	TMERGE
	IEND=1	TMERGE
	GO TO 340	TMERGE
320	CALL CHECK(5,CARD2,KCFL)	TMERGE
	NO=LINEC*100+ICOLC	TMERGE
	IF(NO .EQ. NOP) GO TO 300	TMERGE
340	IF(INSERT .EQ. 0) GO TO 710	TMERGE
	INSERT=0	TMERGE
	GO TO 700	TMERGE
C	INSERT AFTER LAST COLUMN OF PREVIOUS LINE. BACKSPACE TO	TMERGE
600	BACKSPACE M	TMERGE
	BACKSPACE M	TMERGE
	READ(M,605) KEY3,ICONT	TMERGE
605	FORMAT(2A1)	TMERGE
	IF(.NOT. MRGCRD(KEY3)) GO TO 600	TMERGE
	IF(ICONT .EQ. C) GO TO 600	TMERGE
630	BACKSPACE K	TMERGE

	BACKSPACE K	TMERGE
	READ(K,110) REC	TMERGE
	DECODE(2,605,REC) KEYR,ICONT	TMERGE
	IF(.NOT. MRGCRD(KEYR)) GO TO 630	TMERGE
	IF(ICONT .EQ. C) GO TO 630	TMERGE
	DECODE(7,150,REC) KEYR,LINER,ICOLR	TMERGE
	CALL CHECK(K,REC2,KRFL)	TMERGE
	IF(LINER .EQ. LINEC .AND. ICOLR .LT. ICOLC) GO TO 640	TMERGE
	WRITE(6,635) REC,CARD,CARD2,REC2	TMERGE
	WRITE(6,TEST)	TMERGE
635	FORMAT(16HUNABLE TO MATCH/(1X,8A10))	TMERGE
	GO TO 800	TMERGE
640	WRITE(M,110) CARD	TMERGE
	IF(KCFL .NE. 0) WRITE(M,110) CARD2	TMERGE
	LINEP=LINEC	TMERGE
	READ(5,110) CARD	TMERGE
	DECODE(7,150,CARD) KEYC,LINEC,ICOLC	TMERGE
	IF(.NOT. MRGCRD(KEYC)) GO TO 800	TMERGE
	CALL CHECK(5,CARD2,KCFL)	TMERGE
	IF(LINEC .EQ. LINEP) GO TO 640	TMERGE
	GO TO 710	TMERGE
C		TMERGE
700	WRITE(M,110) REC	TMERGE
	IF(KRFL .NE. 0) WRITE(M,110) REC2	TMERGE
	IF(IEND .EQ. 1) GO TO 800	TMERGE
710	READ(K,110) REC	TMERGE
	DECODE(1,150,REC) KEYR	TMERGE
	IF(KEYR .EQ. 1HE) GO TO 810	TMERGE
	IF(MRGCRD(KEYR)) GO TO 720	TMERGE
	KRFL=0	TMERGE
	GO TO 700	TMERGE
720	DECODE(7,150,REC) KEYR,LINER,ICOLR	TMERGE
	CALL CHECK(K,REC2,KRFL)	TMERGE
	NOR=100*LINER+ICOLR	TMERGE
	IF(NOR .EQ. NOR) GO TO 710	TMERGE
	IF(IEND .EQ. 1) GO TO 700	TMERGE
	GO TO 200	TMERGE
C		TMERGE
800	BACKSPACE 5	TMERGE
805	READ(K,110) REC	TMERGE
	IF(EOF(K))820,810	TMERGE
810	WRITE(M,110) REC	TMERGE
	GO TO 805	TMERGE
820	ENDFILE M	TMERGE
	REWIND M	TMERGE
	REWIND K	TMERGE
	RETURN	TMERGE
	END	TMERGE
	FUNCTION ROUND(X).	ROUND
C	THIS FUNCTION WILL ROUND A REAL TO TWO DECIMAL PLACES,	ROUND
	X100=X*100.	ROUND
	NUM=X100	ROUND
	FNUM=FLOAT(NUM)	ROUND
	REMAIN=X100-FNUM	ROUND
	ROUND=FNUM*.01	ROUND
	IF(REMAIN .GT. .5) ROUND=ROUND+.01	ROUND
	RETURN	ROUND
	END	ROUND
	FUNCTION VALUE(IWORD,NNBC)	VALUE
C	THIS FUNCTION FIND THE VALUE OF THE TERM PARAMETER OR COEFFICIENT	VALUE

C	IWORD	TERM, PARAMETER OR COEFFICIENT	VALUE
C	NNBC	NUMBER OF NON-BLANK CHARACTERS	VALUE
C			VALUE
	COMMON LINE, ICOL, LOOPB, LOOPE, KEY, NREAP, TEMP		VALUE
	COMMON /SUMPRT/ ISUM, PRTSUM(12), KEYS		VALUE
	COMMON /ZCARD/ IP, IC, PARAM(10), COEF(10)		VALUE
	EQUIVALENCE (JWORD, RWORD)		VALUE
	LOOPBT=LOOPB		VALUE
	LOOPET=LOOPE		VALUE
	KEYT=KEY		VALUE
	KEYST=KEYS		VALUE
	TEMPT=TEMP		VALUE
	LOOPB=LOOPE=1		VALUE
	KEY=KEYS=1H2		VALUE
	JWORD=IWORD		VALUE
	TEMP=RWORD		VALUE
	CALL GETPAR		VALUE
	VALUE=0.		VALUE
	IF (IC .EQ. 1) VALUE=COEF(1)		VALUE
	IF (IP .EQ. 1) VALUE=PARAM(1)		VALUE
	KEY=KEYT		VALUE
	KEYS=KEYST		VALUE
	TEMP=TEMPT		VALUE
	LOOPB =LOOPBT		VALUE
	LOOPE=LOOPET		VALUE
	RETURN		VALUE
	END		VALUE
	SUBROUTINE EQEVAL (IAL, NW, ANS)		EQEVAL
C			EQEVAL
C	THIS SUBROUTINE IS THE DRIVER FOR THE 'F' CARD		EQEVAL
C	IAL	LOCATION OF FIRST INPUT WORD	EQEVAL
C	NW	NUMBER OF WORDS	EQEVAL
C	ANS	ANSWER	EQEVAL
	COMMON /EQU/ IA(150)		EQEVAL
	DIMENSION IAL(1), RIA(150), IB(20)		EQEVAL
	INTEGER B1, B2, B3		EQEVAL
	EQUIVALENCE (RIA, IA)		EQEVAL
	DO 5 I=1, 150		EQEVAL
5	IA(I)=1R		EQEVAL
	CALL UNPAK (IAL, IA, NW, NC)		EQEVAL
	B1=B2=B3=0		EQEVAL
	DO 50 I=1, NC		EQEVAL
	IF (IA(I) .NE. 1R()) GO TO 10		EQEVAL
	B1=B1+1		EQEVAL
	IB(B1)=I		EQEVAL
10	IF (IA(I) .EQ. 1R()) B3=1		EQEVAL
	IF (IA(I) .NE. 1R()) GO TO 50		EQEVAL
	IF (B3 .EQ. 0) GO TO 40		EQEVAL
	B2=IB(B1)+1		EQEVAL
	B3=B3-1		EQEVAL
	IWORD=IPACK (IA, B2, B3, NNBC)		EQEVAL
	ANS1=VALUE (IWORD, NNBC)		EQEVAL
20	RIA(B2-1)=ANS1		EQEVAL
	DO 30 K=B2, 1		EQEVAL
30	IA(K)=1R		EQEVAL
	B1=B1-1		EQEVAL
	B3=0		EQEVAL
	GO TO 50		EQEVAL
40	B2=IB(B1)+1		EQEVAL
	B3=B3-1		EQEVAL

CALL EXPR(B2,B3,ANS1)	EQEVAL
GO TO 20	EQEVAL
50 CONTINUE	EQEVAL
IF(B1 .NE. 0) GO TO 910	EQEVAL
B2=1	EQEVAL
CALL EXPR(B2,NC,ANS)	EQEVAL
RETURN	EQEVAL
910 PRINT 1, (IAL(1),I=1,NW)	EQEVAL
1 FORMAT(* UNBALANCED PARENTHESES*,/1X,8A10,/1X,7A10)	EQEVAL
ANS=0.0	EQEVAL
RETURN	EQEVAL
END	EQEVAL
FUNCTION IPACK(IA,M,N,NNBC)	IPACK
C THIS FUNCTION PACKS DATA FOR INPUT TO GETPAR	IPACK
C IA INPUT DATA	IPACK
C M START OF DATA	IPACK
C N END OF DATA	IPACK
C NNBC NUMBER OF NON-BLANK CHARACTERS	IPACK
DIMENSION IA(1)	IPACK
JFLG=0	IPACK
IFG=0	IPACK
IF((M .LT. 1) .OR. (N .GT. 150)) GO TO 940	IPACK
IF((IA(M) .LT. 1R0) .OR. (IA(M) .GT. 1R.)) IFG=1	IPACK
IF((IA(M) .GT. 1R-) .AND. (IA(M) .LT. 1R.)) IFG=1	IPACK
NN=N	IPACK
IAN=NNBC+0	IPACK
IB=1R	IPACK
IQ=0	IPACK
IFLG=1R,	IPACK
DO 10 I=M,N,	IPACK
IF((IA(I) .LT. 1R2) .AND. (IA(I) .GT. 0)) JFLG=1	IPACK
IF((IA(I) .EQ. IB) .AND. (JFLG .EQ.0)) GO TO 10	IPACK
IF((NNBC.EQ.10).AND.(IA(I).NE.IB))GO TO 910	IPACK
IF((NNBC.EQ.10).AND.(IA(I).EQ.IB))GO TO 10	IPACK
IT=IA(I)	IPACK
IF((IT .NE. IB) .OR. (JFLG .NE. 1) .OR. (IQ .EQ. 30)) GO TO 8	IPACK
5 IF(IQ - 30) 10,8,6	IPACK
6 NNBC=NNBC+1	IPACK
IQ=IQ-6	IPACK
IPACK=10H1.	IPACK
IP=0	IPACK
IP=MX1FI(IT,IQ)	IPACK
IAN=IAN+IP	IPACK
GO TO 5	IPACK
8 CONTINUE	IPACK
IF(IT .EQ. 1R.) IFG=1	IPACK
IF(IT .EQ. 1R.) IT=IA(I)=IFLG=1R	IPACK
NNBC=NNBC+1	IPACK
IQ=IQ-6	IPACK
IP=0	IPACK
IP=MX1FI(IT,IQ)	IPACK
IAN=IAN+IP	IPACK
10 CONTINUE	IPACK
IF(NNBC .EQ. 0) GO TO 920	IPACK
IF(IFG .EQ. 1) GO TO 12	IPACK
IF(IFLG .EQ. 1B) GO TO 12	IPACK
NNBC=NNBC+1	IPACK
IT=1R.	IPACK
IQ=IQ-6	IPACK
IP=0	IPACK

	IP=MXIFT(IT,IQ)	IPACK
	IAN5=IAN5+IP	IPACK
12	L=NNBC+1	IPACK
	IF(L-10) 15,30,40	IPACK
15	DO 20 I=L,9	IPACK
	IQ=IQ-6	IPACK
	IP=0	IPACK
	IP=MXIFT(IB,IQ)	IPACK
20	IAN5=IAN5+IP	IPACK
30	IAN5=IAN5+IB	IPACK
40	IPACK=IAN5	IPACK
	RETURN	IPACK
910	PRINT 1, IAN5	IPACK
	1 FORMAT(* FUNCTION IPACK DETECTED A VARIABLE NAME OR NUMERIC CONSTA	IPACK
	NT,/1X,*MORE THAN TEN CHARACTERS LONG,(*,A10,*),*/1X,*A VALUE 0	IPACK
	F (1.) WAS SUBSTITUTED AND PROCESSING CONTINUED.)	IPACK
	NNBC=2	IPACK
	RETURN	IPACK
920	PRINT 2	IPACK
	2 FORMAT(* FUNCTION IPACK DETECTED A BLANK VARIABLE NAME OR NUMERIC	IPACK
	CONSTANT./1X,*A VALUE OF (0.) WAS SUBSTITUTED AND PROCESSING CON	IPACK
	TINUED.)	IPACK
925	IPACK=10H0.	IPACK
	NNBC=2	IPACK
	RETURN	IPACK
930	PRINT 3	IPACK
	3 FORMAT(* FUNCTION IPACK DETECTED AN INTEGER MORE THAN NINE CHARACT	IPACK
	ERS LONG./1X,*A VALUE OF (0) WAS SUBSTITUTED AND PROCESSING CONTI	IPACK
	NUED.)	IPACK
	GO TO 925	IPACK
940	PRINT 4	IPACK
	4 FORMAT(* FUNCTION IPACK DETECTED (M .LT. 1) .OR. (N .GT. 150)*)	IPACK
	X1=0.	IPACK
	X2=1.	IPACK
	X2=X2/X1	IPACK
	X1=X2+X1	IPACK
	CALL EXIT	IPACK
	END	IPACK
	SUBROUTINE UNPAK(IAL,IA,NW,NC)	UNPAK
C	THIS SUBROUTINE PUTS DATA INTO NC SEPARATE WORDS	UNPAK
C	IAL LOCATION OF FIRST WORD	UNPAK
C	IA ARRAY OF 150 WORDS	UNPAK
C	NW NUMBER OF WORDS ON INPUT	UNPAK
C	NC NUMBER OF WORDS ON OUTPUT	UNPAK
	DIMENSION IAL(1),IA(1)	UNPAK
	NC=K=0	UNPAK
	L=1	UNPAK
	DO 20 I=1,NW	UNPAK
	NC=NC+10	UNPAK
	DO 20 J=1,10	UNPAK
	K=K+1	UNPAK
	IA(K)=MXGET(IAL(I),J,L)	UNPAK
10	CONTINUE	UNPAK
20	CONTINUE	UNPAK
	K=NC	UNPAK
	DO 30 I=1,K	UNPAK
	L=K-I+1	UNPAK
	IF(IA(L) .NE. 1R) GO TO 40	UNPAK
30	NC=NC-1	UNPAK
40	RETURN	UNPAK

END
 FUNCTION TERM(ITERM)

UNPAK

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C
C      THIS ROUTINE COMPUTES THE TERM
COMMON LINE,ICOL,LOOPB,LOOPE,KEY,NREAP,TEMP(16),SAV(800,13)
COMMON /ZCARD/ IP,IC,PARAM(10),COEF(10)
COMMON/ITERMS/JTERM
SUMP=0.
TERM=0.
JTERM = ITERM
IF(ITERM .EQ. 29) GO TO 2425
IF(ITERM.LE.0.OR.ITERM.GT.28)GO TO 10999
GO TO( 100, 200, 300, 400, 500, 600, 700, 800, 900,1000,
1 1100,1200,1300,1400,1500,1600,1700,1800,1900,2000,2100,
2 2200,2300,2400,2500,2600,2700,2800,
* 11000) ,ITERM
100 CONTINUE
C      TERM=0.
GO TO 11000
200 CONTINUE
C      TERM=C1
DECODE(10,210,TEMP(LOOPB)) COEF(1)
210 FORMAT(7E10.0)
TERM=COEF(1)
GO TO 11000
300 CONTINUE
C      TERM=P1
CALL GETPAR
DO 310 I=1,IP
SUMP=SUMP+PARAM(I )
310 CONTINUE
TERM=SUMP
GO TO 11000
400 CONTINUE
C      TERM=C1*P1
CALL GETPAR
DO 410 I=1,IP
SUMP=SUMP+PARAM(I )
410 CONTINUE
TERM=SUMP*COEF(1)
GO TO 11000
500 CONTINUE
C      TERM=C1*C2
DECODE(20,210,TEMP(LOOPB)) COEF(1),COEF(2)
TERM=COEF(1)*COEF(2)
GO TO 11000
600 CONTINUE
C      TERM=C1*C2*P1
CALL GETPAR
DO 610 I=1,IP
SUMP=SUMP+PARAM(I)
610 CONTINUE
TERM=COEF(1)*COEF(2)*SUMP
GO TO 11000
700 CONTINUE
C      TERM=C1*P1**C2
CALL GETPAR
DO 710 I=1,IP
SUMP=SUMP+PARAM(I)
710 CONTINUE

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        TERM=COEF(1)*SUMP**COEF(2)
        GO TO 11000
800  CONTINUE
C          TERM=C1*C2*C3
        DECODE(30,210,TEMP(LOOPB))(COEF(I),I=1,3)
        TERM=COEF(1)*COEF(2)*COEF(3)
        GO TO 11000
900  CONTINUE
C          TERM=C1*C2*C3*P1
        CALL GETPAR
        DO 910 I=1,IP
            SUMP=SUMP+PARAM(I)
910  CONTINUE
        TERM=COEF(1)*COEF(2)*COEF(3)*SUMP
        GO TO 11000
1000 CONTINUE
C          TERM=C1*C2*P1**C3
        CALL GETPAR
        DO 1010 I=1,IP
            SUMP=SUMP+PARAM(I)
1010 CONTINUE
        TERM=COEF(1)*COEF(2)*SUMP**COEF(3)
        GO TO 11000
1100 CONTINUE
C          TERM=C1*(C2*P1)**C3
        CALL GETPAR
        DO 1110 I=1,IP
            SUMP=SUMP+PARAM(I)
1110 CONTINUE
        TERM=COEF(1)*(COEF(2)*SUMP)**COEF(3)
        GO TO 11000
1200 CONTINUE
C          TERM=C1*C2*P1*(P2/P3)**C3
        CALL GETPAR
        TERM=COEF(1)*COEF(2)*PARAM(1)*(PARAM(2)/PARAM(3))**COEF(3)
        GO TO 11000
1300 CONTINUE
C          TERM=C1*C2*C3*C4
        DECODE(40,210,TEMP(LOOPB))(COEF(I),I=1,4)
        TERM=COEF(1)*COEF(2)*COEF(3)*COEF(4)
        GO TO 11000
1400 CONTINUE
C          TERM=C1*C2*C3**C4
        DECODE(40,210,TEMP(LOOPB))(COEF(I),I=1,4)
        TERM=COEF(1)*COEF(2)*COEF(3)**COEF(4)
        GO TO 11000
1500 CONTINUE
C          TERM=C1*C2*C3*P1**C4
        CALL GETPAR
        DO 1510 I=1,IP
            SUMP=SUMP+PARAM(I)
1510 CONTINUE
        TERM=COEF(1)*COEF(2)*COEF(3)*SUMP**COEF(4)
        GO TO 11000
1600 CONTINUE
C          TERM=C1*C2*(C3 *P1)**C4
        CALL GETPAR
        DO 1610 I=1,IP
            SUMP=SUMP+PARAM(I)
1610 CONTINUE

```

```

        TERM=COEF(1)*COEF(2)*(COEF(3)*SUMP)**COEF(4)
        GO TO 11000
1700 CONTINUE
C          TERM=C1*C2*(P1/C3)**C4
        CALL GETPAR
        DO 1710 I=1,IP
        SUMP=SUMP+PARAM(I)
1710 CONTINUE
        TERM=COEF(1)*COEF(2)*(SUMP/COEF(3))**COEF(4)
        GO TO 11000
1800 CONTINUE
C          TERM=C1*P1*P2
        CALL GETPAR
        TERM=COEF(1)*PARAM(1)*PARAM(2)
        GO TO 11000
1900 CONTINUE
C          TERM=C1*P1*P2*P4/P3
        CALL GETPAR
        TERM=COEF(1)*PARAM(1)*PARAM(2)*PARAM(4)/PARAM(3)
        GO TO 11000
2000 CONTINUE
C          TERM=C1*C2*P1/P2
        CALL GETPAR
        IF (PARAM(2) .EQ. 0.0) GO TO 11000
        TERM=COEF(1)*COEF(2)*PARAM(1)/PARAM(2)
        GO TO 11000
2100 CONTINUE
C          TERM=C1*C2*P1* P2**C3
        TERM = 0.0
        CALL GETPAR
        IF (PARAM(2) .EQ. 0.0) GO TO 11000
        TERM=COEF(1)*COEF(2)*PARAM(1)*PARAM(2)**COEF(3)
        GO TO 11000
2200 CONTINUE
C          TERM=C1*C2*P1**C3*P2**C4
        CALL GETPAR
        IF (PARAM(1) * PARAM(2) .EQ. 0.0) GO TO 11000
        TERM=COEF(1)*COEF(2)*(PARAM(1)**COEF(3))*(PARAM(2)**COEF(4))
        GO TO 11000
2300 CONTINUE
C          TERM=C1*C2*(P1/P2)**C3
        CALL GETPAR
        IF (PARAM(2) .EQ. 0.0) GO TO 11000
        TERM=COEF(1)*COEF(2)*(PARAM(1)/PARAM(2))**COEF(3)
        GO TO 11000
2400 CONTINUE
C          CRAWFORD-LOG LINEAR UNIT LEARNING EQN
C          IF P2 LE 20      TERM= P1*SUM(I**X) I=1,IFIX(P2)
C                           + P1 * (P2 - FLOAT(IFIX(P2)))
C                           * (IFIX(P2) + 1)**X)
C          GT 20      TERM=P1*((P2**(X+1)-1.)/(X+1)
C                           +(P2**X+1.)/2.)
C          WHERE      X  = LN(P3)/LN(2)
        CALL GETPAR
        DECODE(10,211,TEMP(LOOPB)) KLINE,KCOL
211 FORMAT(1X,I3,1X,I2)
        PARAM(1) = SAV(KLINE,KCOL)
        IF (PARAM(2) .LE. 0.) GO TO 11000
        X=ALOG(PARAM(3))/ALOG(2.0)          204
        IP2=IFIX(PARAM(2))

```

```

        IF(IP2.GT.20)GO TO 2410
        SUMP=0.0
        DO 2420 I=1,IP2
        TERM=I
        SUMP=SUMP+TERM**X
2420  CONTINUE
        SUMP = SUMP + (PARAM(2) - FLOAT(IP2)) * (FLOAT(IP2+1))**X
        TERM=PARAM(1)*SUMP
        GO TO 11000
2410  TERM=PARAM(1)*((PARAM(2)**(X+1.)-1.)/(X+1.)+(PARAM(2)**X+1.)/2.)
        GO TO 11000
2425  CONTINUE
C
C      SAME AS EQ. 24 BUT P1 AND P2 CAN BE ANY VALUES.
C
        CALL GETPAR
        DECODE(10,211,TEMP(LOOPB)) KLINE,KCOL
        PARAM(1) = SAV(KLINE,KCOL)
        IF(PARAM(2) .LE. 0.) GO TO 11000
        X = ALOG(PARAM(4)) / ALOG(2.0)
        IP1 = IFIX(PARAM(2))
        IP2 = IFIX(PARAM(3))
        SUMP = 0.0
        DO 2450 I=IP1,IP2
        TERM = I
        SUMP = SUMP + TERM**X
2450  CONTINUE
        SUMP = SUMP + (PARAM(3) - FLOAT(IP2)) * (FLOAT(IP2+1))**X
        TERM = PARAM(1) * SUMP
        GO TO 11000
2500  CONTINUE
C
C      TERM= P1*P2**(X+1)
C      *RIGHT LOG-LINEAR CUMM. AVG. LEARNING EQN
C      WHERE X= LN(C1)/LN(2)
        CALL GETPAR
        IF(COEF(1).EQ.0.0)GO TO 10997
        X=ALOG(COEF(1))/ALOG(2.0)
        TERM=PARAM(1)*PARAM(2)**(X+1.0)
        GO TO 11000
2600  CONTINUE
C      SAV(LINR,ICOL)=SAV(LINE,ICOL)*C(I)*P(I)
C      WHERE I=1,MAXO(IC,IP)
        TERM=0.0
        CALL GETPAR
        IF(IP.EQ.0)GO TO 2610
        DO 2605 I=1,IP
        SAV(LINE,ICOL)=SAV(LINE,ICOL)*PARAM(I)
2605  CONTINUE
2610  IF(IC.EQ.0)GO TO 11000
        DO 2615 I=1,IC
        SAV(LINE,ICOL)=SAV(LINE,ICOL)*COEF(I)
2615  CONTINUE
        GO TO 11000
2700  CONTINUE
C      TERM=C1*C2*(P1/P2)**C3*P3**C4
        CALL GETPAR
        TERM=COEF(1)*COEF(2)*(PARAM(1)/PARAM(2))**COEF(3)*PARAM(3)**COEF(4
        *)
        GO TO 11000
2800  CONTINUE

```

```

C      CRAWFORD LOG-LINEAR LEARNING WITH PRIOR PRODUCTION AND
C      DIFFERING LEARNING SLOPES
      CALL GETPAR
      IF (PARAM(2) .LE. 0.) GO TO 11000
      X1 = ALOG(PARAM(4)) / ALOG(2.0)
      X2 = ALOG(PARAM(5)) / ALOG(2.0)
      IF (PARAM(3) - PARAM(2) - 20.) 2805,2805,2820
2805  SUMP = 0.
      N1 = IFIX(PARAM(2)) + 1 $ N2 = IFIX(PARAM(2)) + IFIX(PARAM(3))
      DO 2810 I=N1,N2
      TERM = I
      SUMP = SUMP + TERM**X2
2810  CONTINUE
      SUMP = SUMP + (PARAM(2) + PARAM(3) - FLOAT(N2)) *(FLOAT(N2+1))**X2
      GO TO 2830
2820  P1 = PARAM(2) + 1. $ P2 = PARAM(2) + PARAM(3)
      SUMP = (P2**X2+1.-P1**X2)/(X2+1.) + (P1**X2+P2**X2)/2.
2830  TERM = PARAM(1) * PARAM(2)**(X1-X2) * SUMP
11000 CONTINUE
      JTERM=1H
      RETURN
10997 PRINT 10996,LINE,ICOL
10996 FORMAT(*0 ON LINE*,I4,* COLUMN*,I3,* THE VALUE OF C1 IS ZERO*)
      TERM=0.0
      RETURN
10998 FORMAT(*0*,20X,*TERM = *,I5,* THIS VALUE IS NOT PERMISSABLE*)
10999 PRINT 10998,ITERM
      TERM=0.0
      RETURN
      END
      SUBROUTINE READW
C ** ** THIS SUBROUTINE READS INPUT VARIABLES FROM SIZE NAMELIST
C
      COMMON LINE,ICOL,LOOPB,LOOPE,KEY,NREAP,TEMP(16),SAV(800,13)
      COMMON/WEIGHT/MAXW,IWD,JWD,WLIST(350),ELIST(6),PL(2100),TYPE(5)
      COMMON/BLOCKW/
1      W1 ,CF1 ,W2 ,CF2 ,W3 ,CF3 ,WT ,W4 ,CF4 ,
2      W5 ,CF5 ,W6 ,CF6 ,WT1 ,W7 ,CF7 ,W8 ,CF8 ,
3      W9 ,CF9 ,WT2 ,CM1 ,CM2 ,CM3 ,CM4 ,CM5 ,CM6 ,
4      CM7 ,CM8 ,CM9 ,CN ,RN ,SNE ,SNI ,SPE ,RP ,
5      TJ4 ,TS4 ,FF1 ,FF2 ,CB1 ,WD1 ,CC1 ,CB2 ,WD2 ,
6      CC2 ,CB3 ,WD3 ,CC3 ,CB4 ,WD4 ,CC4 ,CB5 ,WD5 ,
7      CC5 ,CB6 ,WD6 ,CC6 ,CB7 ,WD7 ,CC7 ,CB8 ,WD8 ,
8      CC8 ,CB9 ,WD9 ,CC9 ,CB10 ,WD10 ,CC10 ,CB11 ,WD11 ,
9      CC11 ,CB12 ,WD12 ,CC12 ,CB13 ,WD13 ,CC13 ,CB14 ,WD14 ,
*      CC14 ,CB15 ,WD15 ,CC15 ,CB16 ,WD16 ,CC16 ,CB17 ,WD17 ,
1      CC17 ,WRRP ,CSO ,FSL ,ERL ,RSL ,TJ7 ,TS7 ,FF3 ,
2      CMB ,AS2 ,RMC1 ,RMC2 ,RMC3 ,SF1 ,SF2 ,SF3 ,RMC4 ,
3      RMC5 ,RMC6 ,SF4 ,SF5 ,SF6 ,RMC7 ,RMC8 ,RMC9 ,SF7 ,
4      SF8 ,SF9 ,RMC10 ,SF10 ,RMC11 ,SF11 ,RMC12 ,SF12 ,RMC13 ,
5      SF13 ,RMC14 ,SF14 ,RMC15 ,SF15 ,RMC16 ,SF16 ,RMC17 ,SF17 ,
6      RMC18 ,SF18 ,RMC19 ,SF19 ,RMC20 ,SF20 ,RMC21 ,SF21 ,RMC22 ,
7      SF22 ,RMC23 ,SF23 ,RMC24 ,SF24 ,RMC25 ,SF25 ,RMC26 ,SF26 ,
8      FM1 ,FM2 ,EH ,WAMPR ,TMF ,ECLR ,TAM ,RM ,THC ,
9      TEC ,TDC ,RQC ,RT ,PN1 ,PN2 ,PN3 ,PN4 ,PN5 ,PN6
      COMMON/BLOCKC/
1      PC11 ,PC12 ,PC13 ,PC14 ,PC15 ,PC16 ,PC17 ,PC18 ,PC19 ,
2      PC110 ,PC111 ,PC112 ,PC113 ,PC114 ,PC115 ,PC116 ,PC117 ,PC118 ,
3      PC119 ,PC120 ,PC121 ,PC21 ,PC22 ,PC23 ,PC24 ,PC25 ,PC26 ,
4      PC27 ,PC28 ,PC29 ,PC210 ,PC211 ,PC212 ,PC213 ,PC214 ,PC215 ,

```

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5 PC216 ,PC217 ,PC218 ,PC219 ,PC220 ,PC221 ,PC231 ,PC32 ,PC33 ,
6 PC34 ,PC35 ,PC36 ,PC37 ,PC38 ,PC39 ,PC310 ,PC311 ,PC312 ,
7 PC313 ,PC314 ,PC315 ,PC316 ,PC317 ,PC318 ,PC319 ,PC320 ,PC321
COMMON/BLOCKS/
1 WW ,WH ,WV ,WF ,WN ,WL ,E1 ,E2 ,F1 ,
2 F2 ,F3 ,F4 ,F5 ,F6 ,F7 ,WAMP ,F8 ,WS ,
3 F9 ,WEC ,F10 ,WHP ,F11 ,WE1 ,F12 ,W1 ,F13 ,
4 WAP ,F14 ,WA ,F15 ,WEA ,F16 ,WFS ,F17 ,WAD ,
5 F18 ,FW ,ECLR1 ,FM ,T1 ,TF1 ,TF2 ,TF3 ,TF4 ,
6 TF5 ,TF6 ,TF7 ,R ,TH ,TMLR ,TEF ,RTEF ,TELR ,
7 TMF2 ,MAF ,MALR ,MDF ,MDLR ,S ,QD ,RI ,Y ,
8 QCF1 ,QCF2 ,QCLR2 ,W ,UF1 ,UF2 ,UF3 ,UF4 ,UF5 ,UF6 ,
9 UF7 ,UF8 ,UF9 ,UF10 ,UF11 ,UF12 ,UF13 ,UF14 ,UF15 ,
* UF16 ,UF17 ,QN1 ,QN2 ,QN3 ,QN4 ,QN5 ,QN6 ,ES ,
1 ECLR2 ,TU ,TMEC ,QC11 ,QC21 ,QC31 ,QC12 ,QC22 ,QC32 ,
2 QC13 ,QC23 ,QC33 ,QC14 ,QC24 ,QC34 ,QC15 ,QC25 ,QC35 ,
3 QC16 ,QC26 ,QC36 ,QC17 ,QC27 ,QC37
DIMENSION PTEMP(172),PTEMP2(63),PTEMP3(115)
EQUIVALENCE(PTEMP,W1)
EQUIVALENCE(PTEMP2,PC11)
EQUIVALENCE(PTEMP3,WW)
REAL MAF,MALR,MDF,MDLR

```

C **

```

DATA (WLIST(I),I=1,70)/
1 6HW1 ,6HCF1 ,6HW2 ,6HCF2 ,6HW3 ,6HCF3 ,6HWT ,
2 6HW4 ,6HCF4 ,6HW5 ,6HCF5 ,6HW6 ,6HCF6 ,6HWT1 ,
3 6HW7 ,6HCF7 ,6HW8 ,6HCF8 ,6HW9 ,6HCF9 ,6HWT2 ,
4 6HCM1 ,6HCM2 ,6HCM3 ,6HCM4 ,6HCM5 ,6HCM6 ,6HCM7 ,
5 6HCM8 ,6HCM9 ,6HCN ,6HRN ,6HSNE ,6HSNI ,6HSPE ,
6 6HRP ,6HTJ4 ,6HTS4 ,6HFF1 ,6HFF2 ,6HCB1 ,6HWD1 ,
7 6HCC1 ,6HCB2 ,6HWD2 ,6HCC2 ,6HCB3 ,6HWD3 ,6HCC3 ,
8 6HCB4 ,6HWD4 ,6HCC4 ,6HCB5 ,6HWD5 ,6HCC5 ,6HCB6 ,
9 6HWD6 ,6HCC6 ,6HCB7 ,6HWD7 ,6HCC7 ,6HCB8 ,6HWD8 ,
* 6HCC8 ,6HCB9 ,6HWD9 ,6HCC9 ,6HCB10 ,6HWD10 ,6HCC10 /
DATA (WLIST(I),I=71,140)/
1 6HCB11 ,6HWD11 ,6HCC11 ,6HCB12 ,6HWD12 ,6HCC12 ,6HCB13 ,
2 6HWD13 ,6HCC13 ,6HCB14 ,6HWD14 ,6HCC14 ,6HCB15 ,6HWD15 ,
3 6HCC15 ,6HCB16 ,6HWD16 ,6HCC16 ,6HCB17 ,6HWD17 ,6HCC17 ,
4 6HWRRP ,6HCS0 ,6HFSL ,6HERL ,6HRSL ,6HTJ7 ,6HTS7 ,
5 6HFF3 ,6HCM8 ,6HAS2 ,6HRMC1 ,6HRMC2 ,6HRMC3 ,6HSF1 ,
6 6HSF2 ,6HSF3 ,6HRMC4 ,6HRMC5 ,6HRMC6 ,6HSF4 ,6HSF5 ,
7 6HSF6 ,6HRMC7 ,6HRMC8 ,6HRMC9 ,6HSF7 ,6HSF8 ,6HSF9 ,
8 6HRMC10 ,6HSF10 ,6HRMC11 ,6HSF11 ,6HRMC12 ,6HSF12 ,6HRMC13 ,
9 6HSF13 ,6HRMC14 ,6HSF14 ,6HRMC15 ,6HSF15 ,6HRMC16 ,6HSF16 ,
$ 6HRMC17 ,6HSF17 ,6HRMC18 ,6HSF18 ,6HRMC19 ,6HSF19 ,6HRMC20 /
DATA (WLIST(I),I=141,210)/
1 6HSF20 ,6HRMC21 ,6HSF21 ,6HRMC22 ,6HSF22 ,6HRMC23 ,6HSF23 ,
2 6HRMC24 ,6HSF24 ,6HRMC25 ,6HSF25 ,6HRMC26 ,6HSF26 ,6HFM1 ,
3 6HFM2 ,6HEH ,6HWAMPR ,6HTMF ,6HECLR ,6HTAM ,6HRM ,
4 6HTHC ,6HTEC ,6HTDC ,6HRQC ,6HRT ,6HPN1 ,6HPN2 ,
5 6HPN3 ,6HPN4 ,6HPN5 ,6HPN6 ,6HPC11 ,6HPC12 ,6HPC13 ,
6 6HPC14 ,6HPC15 ,6HPC16 ,6HPC17 ,6HPC18 ,6HPC19 ,6HPC110 ,
7 6HPC111 ,6HPC112 ,6HPC113 ,6HPC114 ,6HPC115 ,6HPC116 ,6HPC117 ,
8 6HPC118 ,6HPC119 ,6HPC120 ,6HPC121 ,6HPC21 ,6HPC22 ,6HPC23 ,
9 6HPC24 ,6HPC25 ,6HPC26 ,6HPC27 ,6HPC28 ,6HPC29 ,6HPC210 ,
$ 6HPC211 ,6HPC212 ,6HPC213 ,6HPC214 ,6HPC215 ,6HPC216 ,6HPC217 /
DATA (WLIST(I),I=211,280)/
1 6HPC218 ,6HPC219 ,6HPC220 ,6HPC221 ,6HPC31 ,6HPC32 ,6HPC33 ,
2 6HPC34 ,6HPC35 ,6HPC36 ,6HPC37 ,6HPC38 ,6HPC39 ,6HPC310 ,
3 6HPC311 ,6HPC312 ,6HPC313 ,6HPC314 ,6HPC315 ,6HPC316 ,6HPC317 ,

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4 6HPC318 ,6HPC319 ,6HPC320 ,6HPC321 ,6HWW ,6HWH ,6HWV ,
5 6HWF ,6HWN ,6HWL ,6HE1 ,6HE2 ,6HF1 ,6HF2 ,
6 6HF3 ,6HF4 ,6HF5 ,6HF6 ,6HF7 ,6HWAMP ,6HFB ,
7 6HWS ,6HF9 ,6HWEC ,6HF10 ,6HWP ,6HF11 ,6HWE1 ,
8 6HF12 ,6HWI ,6HF13 ,6HWAP ,6HF14 ,6HWA ,6HF15 ,
9 6HWEA ,6HF16 ,6HWFS ,6HF17 ,6HWAD ,6HF18 ,6HFW ,
$ 6HECLR1 ,6HFM ,6HT1 ,6HTF1 ,6HTF2 ,6HTF3 ,6HTF4 /

```

DATA (WLIST(I),I=281,350)/

```

1 6HTF5 ,6HTF6 ,6HTF7 ,6HR ,6HTR ,6HTMLR ,6HTEF ,
2 6HTEF ,6HTELR ,6HTMF2 ,6HMAF ,6HMALR ,6HMDF ,6HMDLR ,
3 6HS ,6HQD ,6HRI ,6HY ,6HQCF1 ,6HQCF2 ,6HQCLR2 ,
4 6HW ,6HUF1 ,6HUF2 ,6HUF3 ,6HUF4 ,6HUF5 ,6HUF6 ,
5 6HUF7 ,6HUF8 ,6HUF9 ,6HUF10 ,6HUF11 ,6HUF12 ,6HUF13 ,
6 6HUF14 ,6HUF15 ,6HUF16 ,6HUF17 ,6HQN1 ,6HQN2 ,6HQN3 ,
7 6HQN4 ,6HQN5 ,6HQN6 ,6HES ,6HECLR2 ,6HTU ,6HTMEC ,
8 6HQC11 ,6HQC21 ,6HQC31 ,6HQC12 ,6HQC22 ,6HQC32 ,6HQC13 ,
9 6HQC23 ,6HQC33 ,6HQC14 ,6HQC24 ,6HQC34 ,6HQC15 ,6HQC25 ,
$ 6HQC35 ,6HQC16 ,6HQC26 ,6HQC36 ,6HQC17 ,6HQC27 ,6HQC37 /

```

NAMelist /SIZE/

```

1 w1 ,CF1 ,w2 ,CF2 ,w3 ,CF3 ,wT ,w4 ,CF4 ,
2 w5 ,CF5 ,w6 ,CF6 ,WT1 ,w7 ,CF7 ,w8 ,CF8 ,
3 w9 ,CF9 ,WT2 ,CM1 ,CM2 ,CM3 ,CM4 ,CM5 ,CM6 ,
4 CM7 ,CM8 ,CM9 ,CN ,RN ,SNE ,SNI ,SPE ,RP ,
5 TJ4 ,TS4 ,FF1 ,FF2 ,CB1 ,WD1 ,CC1 ,CB2 ,WD2 ,
6 CC2 ,CB3 ,WD3 ,CC3 ,CB4 ,WD4 ,CC4 ,CB5 ,WD5 ,
7 CC5 ,CB6 ,WD6 ,CC6 ,CB7 ,WD7 ,CC7 ,CB8 ,WD8 ,
8 CC8 ,CB9 ,WD9 ,CC9 ,CB10 ,WD10 ,CC10 ,CB11 ,WD11 ,
9 CC11 ,CB12 ,WD12 ,CC12 ,CB13 ,WD13 ,CC13 ,CB14 ,WD14 ,
$ CC14 ,CB15 ,WD15 ,CC15 ,CB16 ,WD16 ,CC16 ,CB17 ,WD17 ,
1 CC17 ,WRRP ,CS0 ,FSL ,ERL ,RSL ,TJ7 ,TS7 ,FF3 ,
2 CM5 ,AS2 ,RMC1 ,RMC2 ,RMC3 ,SF1 ,SF2 ,SF3 ,RMC4 ,
3 RMC5 ,RMC6 ,SF4 ,SF5 ,SF6 ,RMC7 ,RMC8 ,RMC9 ,SF7 ,
4 SF8 ,SF9 ,RMC10 ,SF10 ,RMC11 ,SF11 ,RMC12 ,SF12 ,RMC13 ,
5 SF13 ,RMC14 ,SF14 ,RMC15 ,SF15 ,RMC16 ,SF16 ,RMC17 ,SF17 ,
6 RMC18 ,SF18 ,RMC19 ,SF19 ,RMC20 ,SF20 ,RMC21 ,SF21 ,RMC22 ,
7 SF22 ,RMC23 ,SF23 ,RMC24 ,SF24 ,RMC25 ,SF25 ,RMC26 ,SF26 ,
8 FM1 ,FM2 ,EH ,WAMPR ,TMF ,ECLR ,TAM ,RM ,THC ,
9 TEC ,TDC ,RQC ,RT ,PN1 ,PN2 ,PN3 ,PN4 ,PN5 ,PN6

```

NAMelist /CURVE/

```

1 PC11 ,PC12 ,PC13 ,PC14 ,PC15 ,PC16 ,PC17 ,PC18 ,PC19 ,
2 PC110 ,PC111 ,PC112 ,PC113 ,PC114 ,PC115 ,PC116 ,PC117 ,PC118 ,
3 PC119 ,PC120 ,PC121 ,PC21 ,PC22 ,PC23 ,PC24 ,PC25 ,PC26 ,
4 PC27 ,PC28 ,PC29 ,PC210 ,PC211 ,PC212 ,PC213 ,PC214 ,PC215 ,
5 PC216 ,PC217 ,PC218 ,PC219 ,PC220 ,PC221 ,PC31 ,PC32 ,PC33 ,
6 PC34 ,PC35 ,PC36 ,PC37 ,PC38 ,PC39 ,PC310 ,PC311 ,PC312 ,
7 PC313 ,PC314 ,PC315 ,PC316 ,PC317 ,PC318 ,PC319 ,PC320 ,PC321

```

NAMelist /SUMARY/

```

1 WW ,WH ,WV ,WF ,WN ,WL ,E1 ,E2 ,F1 ,
2 F2 ,F3 ,F4 ,F5 ,F6 ,F7 ,WAMP ,F8 ,WS ,
3 F9 ,WEC ,F10 ,WHP ,F11 ,WE1 ,F12 ,WI ,F13 ,
4 WAP ,F14 ,WA ,F15 ,WEA ,F16 ,WFS ,F17 ,WAD ,
5 F18 ,FW ,ECLR1 ,FM ,T1 ,TF1 ,TF2 ,TF3 ,TF4 ,
6 TF5 ,TF6 ,TF7 ,R ,TR ,TMLR ,TEF ,RTEF ,TELR ,
7 TMF2 ,MAF ,MALR ,MDF ,MDLR ,S ,QD ,R1 ,Y ,
8 QCF1 ,QCF2 ,QCLR2 ,W ,UF1 ,UF2 ,UF3 ,UF4 ,UF5 ,
9 UF6 ,UF7 ,UF8 ,UF9 ,UF10 ,UF11 ,UF12 ,UF13 ,UF14 ,
$ UF15 ,UF16 ,UF17 ,QN1 ,QN2 ,QN3 ,QN4 ,QN5 ,QN6 ,
1 ES ,ECLR2 ,TU ,TMEC ,QC11 ,QC21 ,QC31 ,QC12 ,QC22 ,
2 QC32 ,QC13 ,QC23 ,QC33 ,QC14 ,QC24 ,QC34 ,QC15 ,QC25 ,
3 QC35 ,QC16 ,QC26 ,QC36 ,QC17 ,QC27 ,QC37

```

```

C **
DATA BLANK/1H /
C **
IWD=350
ICLEAR = 0
IF(JWD .EQ. 0) GO TO 10
ICLEAR = 1
GO TO 30
10 DO 20 I=1,6
IF(TEMP(I) .EQ. BLANK) GO TO 30
DECODE(5,80,TEMP(I)) (TYPE(J),J=1,5)
ELIST(I) = PWORD(TYPE,1,5)
JWD = JWD + 1
20 CONTINUE
C **
DO 25 KIM=1,5
TYPE(KIM) = BLANK
25 CONTINUE
C **
30 DO 70 JJ=1,JWD
IF(ICLEAR .EQ. 0) GO TO 50
DO 40 I=1,IWD
ISUB = (JJ-1) * MAXW + I
IF(I .GE. 236) GO TO 36
IF(I .GE. 173) GO TO 35
PTEMP(I) = PL(ISUB)
GO TO 40
35 KIM = I-172
PTEMP2(KIM) = PL(ISUB)
GO TO 40
36 KIM=I-235
PTEMP3(KIM)=PL(ISUB)
40 CONTINUE
50 CONTINUE
READ(5,SIZE)
READ(5,CURVE)
READ(5,SUMARY)
PN4 = PN2 + PN3
PN6 = PN2 + PN5
QN4=QN2+QN3
QN6=QN2+QN5
DO 60 I=1,IWD
ISUB = (JJ-1) * MAXW + I
IF(I .GE. 236) GO TO 56
IF(I .GE. 173) GO TO 55
PL(ISUB) = PTEMP(I)
GO TO 60
55 KIM = I-172
PL(ISUB) = PTEMP2(KIM)
GO TO 60
56 KIM=I-235
PL(ISUB)=PTEMP3(KIM)
60 CONTINUE
70 CONTINUE
RETURN
C **
80 FORMAT(5A1)
END

```

R

APPENDIX D

COMPUTER PROGRAM FOR DEVELOPMENT OF AIRCRAFT FUSELAGE, LANDING GEAR AND NACELLE WEIGHTS

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SECTION 1

INTRODUCTION

The objective of this study was to develop a digital computer program to predict the structural weight of fuselage and nacelles, and the landing gear group weight for fighter, bomber, and transport aircraft.

The input requirements are to be of the type typically known at the preliminary design level relating to weight, geometry, loads, and dimensionless ratios. The output for the fuselage is developed from an empirical analysis based on statistical data (Reference 1), as well as, semi-analytical analysis that utilizes a multi-station structural analysis (Reference 1) for the basic shell. The nacelle structural weight and landing gear weight outputs are developed by an empirical analysis based on statistical data (Reference 1.)

The math models developed for this study are an assimilation of previously developed equations. The backup data, curves, tables and figures are presented in detail in References 1, 2 and 3.

The program is structured so the user may use all equations, or with the use of a tailoring constant, zero out the equations that are not applicable to his particular vehicle definition.

This program is written in Fortran IV and can be easily adapted for use on a small computer.

SECTION 2

ENGINEERING DISCUSSION

2.1 TASK OBJECTIVE

The objective of this study was to develop a digital computer program to predict the structural weight of fuselage and nacelles, and the landing gear group weight for fighter, bomber, and transport aircraft.

2.2 PURPOSE OF THE PROGRAM

The purpose of this program is to provide fuselage and nacelle structural weights, and landing gear weights to be used in the evaluation of preliminary design aircraft concepts. The stand alone operation of the program allows the user to input data from other analytical programs; and to output data that satisfies this input requirement for cost math models developed under Air Force Contract AF 33615-72-C-2083, "Techniques For Estimating Weapon System Structural Costs".

2.3 PROGRAM REQUIREMENTS

The input requirements of the program are to be of the type typically known at the preliminary design level relating to weight, geometry, loads, and dimensionless ratios. The output for the fuselage is developed from an empirical analysis based on statistical data, as well as, a semi-analytical analysis that utilizes a multi-station structural analysis for the basic shell. The nacelle structural weight and landing gear weight outputs are developed by an empirical analysis based on statistical data.

2.4 MATH MODELS

The math models developed for this study is an assimilation of previously developed equations to provide a computerized output of fuselage and nacelle structural weight and landing gear group weight. The mathematical expressions used in the math models associated with this computer program development is documented in Reference 1.

In the following discussions of the fuselage, nacelle and landing gear math models, the equations and methods are presented in general form and in normal algebraic notation so that they will be easy to follow. In the computer subroutines, the equations and methods are, of course, in Fortran, and they are specific in application. Only the major equations are shown in this section. The sub-equations used to restructure internal equation input is documented only in the computer listing of the specific model as shown in Appendix I.

This section describes the weight calculations that are needed to produce the fuselage structural weight, the nacelle structural weight, and the landing gear weight. The equations listed here are not the only ones that could apply, but they are representative and may be modified or replaced if need be.

2.4.1 FUSELAGE EQUATIONS. The fuselage structural weight is estimated by one or both of two methods. Both methods utilize structural penalties in the development of the final fuselage weight, but differ in the development of the basic shell weight.

The first method estimates the basic shell material required to wrap the body volume and resist local airloads. Body and configuration penalty weights, as well as, special increment weights are added to the basic shell to develop a total fuselage structural weight.

The second method differs from the first only in the derivation of the basic shell weight. The fuselage shell weight is developed by a separate structural synthesis analysis program with the output being provided to this program as input. Body and configuration penalty weights, and special increment weights not accounted for in the structural synthesis are then added, within this program, to develop a total fuselage structural weight.

The equations and definition of terms associated with the first method are documented in the following paragraphs and in Reference 1. The analysis associated with the basic shell weight derivation used in the second method is documented in Reference 2.

Basic Shell (Material Required to Wrap Body Volume and Resist Local Airload)

$$Wt_1 = .87 (q \times 10^{-2})^{.2} S_{FF}$$

Where:

q - Maximum operating dynamic pressure based on V_H - lbs/ft²

S_{FF} - Fuselage aerodynamic wetted area minus summation of large fuselage cutout areas - ft²/AP

Cockpit Provisions

$$Wt_2 = 1.54 (V_C)^{.78} (1 + P_C)^{.35}$$

Where:

V_C - Cockpit Volume - ft³

P_C - Ultimate Cabin Pressure - lbs/in²

Nose Landing Gear Doors

$$Wt_3 = .44 (q)^{.3} S_{ND}$$

Where:

S_{ND} - Nose landing gear door area - ft²

q - Maximum operating dynamic pressure based on V_H - lbs/ft²

Nose Landing Gear Cutout and Load Introduction

$$Wt_4 = .0385 (F_{VN} L_{EX} \times 10^{-3})^{.9}$$

Where:

F_{VN} - Nose landing gear maximum vertical reaction (Ult.) - lbs.

L_{EX} - Nose landing gear extended length

Wing Reaction (Wing Fuselage Tie)

$$Wt_5 = .8 W_{DES} N b' \times 10^{-5}$$

Where:

W_{DES} - Design gross weight - lbs.

N - Flight design load factor (ultimate)

b' - structural span - ft. Measured along .50 chord

Tail Provisions

$$Wt_6 = 6.7 \left[(F_V + F_H) \times 10^{-3} \right]^{.6}$$

Where:

F_H - Ultimate horizontal tail load - lbs.

Windshield and Canopy

$$Wt_{\bar{c}} = K (S_C)^{.656} (1 + P_C)^{.207}$$

Where:

- S_C - Windshield and Canopy area - ft²
- P_C - Ultimate cabin pressure - lbs/in²
- K - 11.6 - single seat canopy
- 17.5 - dual side by side canopy
- 19.9 - multi-seat tandem canopy
- 24.0 - windshield and windows

Forward Vertical Inertia

$$Wt_q = \frac{10.9 W_{FI} N (L_{FL})^2 \times 10^{-6}}{D_{FF}}$$

Where:

- W_{FI} - Wt. of body structure, equipment and useful load (excluding fuel) forward of the \bar{C}_L of the wing structural box - lbs.
- L_{FL} - Forward longeron length - ft. Measured from \bar{C}_L wing box to forward radome bulkhead
- D_{FF} - Forward fuselage average effective vertical bending depth -ft.
- N - Flight design load factor (ultimate)

Aft Vertical Inertia

$$Wt_9 = \frac{10.9 N (W_{AI}) (L_{AL})^2 \times 10^{-6}}{D_{AF}}$$

Where:

W_{AI} - Wt. of body structure, tails and equipment (excluding engines and fuel) aft of \mathcal{C}_L wing structural box - lbs.

L_{AL} - Aft longeron length - ft. Measured from \mathcal{C}_L wing box to end of aft longeron

D_{AF} - Aft fuselage average effective vertical bending depth - ft.

N - Flight design load factor (ultimate)

Forward Side Bending

$$Wt_{10} = \frac{10.9 F_V L_{FL} L_{VT} \times 10^{-6}}{D_{WF}}$$

Where:

L_{VT} - Distance from \mathcal{C}_L wing structural box to \mathcal{C}_L vertical tail structural box or spindle - ft.

D_{WF} - Forward fuselage average effective side bending width -ft.

F_V - Ultimate vertical tail load -lbs

L_{FL} - Forward longeron length - ft. Measured from \mathcal{C}_L wing box to forward radome bulkhead

Aft Side Bending

$$Wt_{11} = \frac{25.9 F_V (L_{VT})^2 \times 10^{-6}}{D_{WA}}$$

Where:

L_{VT} - Distance from \mathcal{C}_L wing structural box to \mathcal{C}_L vertical tail box

D_{WA} - Aft fuselage average effective side bending width - ft.

F_V - Ultimate vertical tail load - lbs

Forward Fuel Inertia

$$Wt_{12} = \frac{25.9 W_{FF} N (L_{FF})^2 \times 10^{-6}}{D_{FF}}$$

Where:

N - Flight design load factor (ultimate)

W_{FF} - Wt. of forward fuselage fuel at design condition - lbs.

L_{FF} - Distance from \mathcal{C}_L wing structural box to center of gravity of forward fuselage fuel tank - ft.

D_{FF} - Forward fuselage average effective vertical bending depth - ft.

Aft Fuel Inertia

$$Wt_{13} = \frac{25.9 W_{FA} N (L_{AF})^2 \times 10^{-6}}{D_{AF}}$$

Where:

N - Flight design load factor (ultimate)

W_{FA} - Wt. of aft fuselage fuel at design condition - lbs.

L_{AF} - Distance from \mathcal{C}_L wing structural box to center of gravity of aft fuselage fuel tank - ft.

D_{AF} - Aft fuselage average effective vertical bending depth - ft.

Aft Engine Bending

$$Wt_{14} = \frac{25.9 W_E N (L_{PP})^2 \times 10^{-6}}{D_{AF}}$$

Where:

N - Flight design load factor (ultimate)

W_E - Wt. of fuselage mounted engine and accessories - lbs.

L_{PP} - Distance from \mathcal{C}_L wing structural box to center of gravity of engines and accessories - ft.

D_{AF} - Aft fuselage average effective vertical bending depth - ft

Aft Horizontal Tail Bending

$$Wt_{15} = \frac{25.9 F_H (L_{HT})^2 \times 10^{-6}}{D_{AF}}$$

Where:

F_H - Ultimate horizontal tail load - lbs

L_{HT} - Distance from \mathcal{C}_L wing structural box to \mathcal{C}_L horizontal tail structural box or spindle - ft.

D_{AF} - Aft fuselage average effective vertical bending depth -ft

Fuel Provisions

$$Wt_{16} = K (G_f)^{.75} (N_f)^{.375}$$

Where.

G_f - Fuselage fuel capacity - gal.

N_f - Number of fuselage tanks

K - .95 Bags
- .75 Integral tanks

Arresting Gear Provisions (Carrier Based)

$$Wt_{17} = .46 D_c \times 10^{-3}$$

Where:

D_c = Ultimate arresting hook drag component - lbs.

Catapult and Holdback - Fuselage Tow

$$Wt_{18} = .192 N_X W_c \times 10^{-3}$$

Where:

N_X = Catapult load factor (ultimate)

W_c = Catapult design gross weight - lbs

Catapult and Holdback - Nose Landing Gear Tow

$$Wt_{19} = .30 \left(\frac{W_c}{W_L} \right)^{1.09} \left(\frac{L_{EX}}{D_{FF}} \right)^2 W_c N_X \times 10^{-6}$$

Where:

W_c = Catapult design gross wt. - lbs.

W_L = Landing design gross wt. - lbs.

L_{EX} = Nose landing gear length, \mathcal{C}_L trunnion to \mathcal{C}_L axle - extended - in.

N_X = Catapult load factor (ultimate)

D_{FF} = Forward fuselage average effective vertical bending

Engine Provisions

$$Wt_{20} = 3.85 (T \times 10^{-3})^6 N_E + 3.24 (L_E D_E N_E)^{.9}$$

Where:

T - Maximum engine thrust - lbs/eng.

N_E - Number of engines

L_E - Engine compartment length - ft

D_E - Engine compartment diameter - ft.

Duct Provisions

$$Wt_{21} = .044 N_D L_D \left(\frac{C_I + C_E}{2} \right)^{1.3} (P_D)^{.6}$$

Where:

N_D - Number ducts

L_D - Duct length at \bar{C}_L - ft/duct

C_I - Duct circumference at inlet - ft/duct

C_E - Duct circumference at engine face - ft/duct

P_D - Ultimate duct pressure - lbs/in²

Main Landing Gear Doors

$$Wt_{22} = K (S_{MD})^{1.125}$$

Where:

K - 3.223 - Separately actuated doors

- 1.788 - Doors actuated and linked to landing gear

S_{MD} - Main landing gear door area - ft²/AP

Main Landing Gear Cutout and/or Load Introduction

$$Wt_{23} = .385 \left[F_{VM} L_{EX} \times 10^{-3} \right]^{.9} \frac{N_{ST}}{S_M}$$

Where:

F_{VM} - Main landing gear maximum vertical reaction (ultimate)
lbs./side

L_{EX} - Main landing gear extended length, ϕ_L trunnion to ϕ_L axle - inches

S_M - Main landing gear stroke - inches

N_{ST} - Number main landing gear struts per A/P

External Stores Provisions

$$Wt_{24} = K_S (W_S)^{.7} N_S$$

Where:

K_S - External store constant
- .067 USAF
- .10 USN

W_S - Maximum or design store wt. - lbs/sta.

N_S - Number of store stations

Speed Brakes

$$Wt_{25} = 1.928 (K N_{SB} S_{SB})^{.98} (q C_D S_{SB} \times 10^{-3})^{.49}$$

Where:

S_{SB} - Speed brake area - ft²/brake

N_{SB} - Number of speed brakes

q - Speed brake design dynamic pressure - lbs/ft²

C_D - Speed brake drag coefficient

K - 1.0 for two brakes per airplane

- .565 for one brake per airplane

Bomb and Missile Bay Cutout

$$Wt_{26} = K_B (N)^{.37} [W_{WE} L_{BM} D_{MB} \times 10^{-4}]^{.494}$$

Where:

W_{WE} - Maximum weapon wt. - lbs.

L_{MB} - Total bomb or missile bay length - ft.

D_{MB} - Bomb or missile bay width - ft.

K_B - Bomb bay type factor - 19.24 Conventional
- 24.05 Rotary

N - Flight design load factor (ultimate)

Bomb and Missile Bay Doors and Mechanism (Conventional)

$$Wt_{27} = 5.65 \left[S_{MB} L_{MB} \right]^{.483} (N)^{.12} (q \times 10^{-2})^{.241}$$

Where:

N - Flight design load factor (ultimate)

S_{MB} - Missile or bomb bay door area - ft²

L_{MB} - Total bomb or missile bay length - ft

q - Maximum operating dynamic pressure based on V_H - lbs/ft²

Bomb and Missile Bay Doors and Mechanism (Rotary)

$$Wt_{28} = \left[S_{MB} L_{MB} \right]^{.758} (N)^{.19} (q \times 10^{-2})^{.38}$$

Where:

N - Flight design load factor (ultimate)

S_{MB} - Missile or bomb bay door area - ft²

L_{MB} - Total bomb or missile bay length - ft

q - Maximum operating dynamic pressure based on V_H - lbs/ft²

Cabin Flooring and Supports (Transports)

$$Wt_{29} = 6.51 \left[N W_f A_f \times 10^{-3} \right]^{.924}$$

Where:

N - Flight design load factor (ultimate)

W_f - 1.0 G Design floor loading - lbs/ft²

A_f - Cabin floor area - ft²

Cabin Windows (Transports)

$$Wt_{30} = K A_{GL}$$

Where:

A_{GL} - Window glass area - ft²/AP

K - Ranges from 5.0 to 10.0 depending on installation. Most likely to be 10.0 if a pressurized transport.

Pressure Web and Sealant (Transports)

$$Wt_{31} = 12.57 S_{WP} P_C \times 10^{-3}$$

Where:

P_C - Ultimate Cabin Pressure - lbs/in²

S_{WP} - Cargo-passenger compartment pressurized wetted area -ft²/AP

Air Extraction Provisions (Transports)

$$Wt_{32} = 24.65 L_{FLR}$$

Where:

L_{FLR} - Cargo Floor length -ft

This penalty includes pallet side rails, conveyors, and rollers.

Cargo Loading Ramps - Actuated (Transports)

$$Wt_{33} = 1.85 \left[S_{RA} L_{RA} W_f \times 10^{-2} \right] .785$$

Where:

S_{RA} - Ramp Area - ft²

L_{RA} - Ramp length - ft.

W_f - 1 G design floor loading - lbs/ft²

Main Landing Gear External Fairings

$$Wt_{34} = .0403 S_{GF} L_{GF} (q \times 10^{-2})^{.25}$$

Where:

q = Maximum operating dynamic pressure based on V_H - lbs/ft²

S_{GF} = Landing gear fairing area - ft²/AP

L_{GF} = Landing gear fairing length - ft

Side Loading Doors and Mechanism

$$Wt_{35} = 9.0 S_{DA}$$

Where:

S_{DA} = Side loading door area - ft²/AP

Clamshell Doors and Mechanism

$$Wt_{36} = 2.75 C_{SDA}$$

Where:

C_{SDA} = Clamshell doors area - ft²/AP

Flat Cargo Clearance Doors

$$Wt_{37} = 9.0 F_{CCDA}$$

Where:

F_{CCDA} = Flat cargo door area - ft²/AP

Fuel Tank Flooring

$$Wt_{38} = 7.25 F_{TFA}$$

Where:

$$F_{TFA} = \text{Fuel tanking flooring area} - \text{ft}^2/\text{AP}$$

Swing Tail or Nose Provisions

$$Wt_{39} = 63.5 C_F$$

Where:

$$C_F = \text{Fuselage circumference} - \text{ft.}$$

Over Wing Fairing

$$Wt_{40} = 1.95 S_{WF}$$

Where:

$$S_{WF} = \text{Over wing fairing area} - \text{ft}^2/\text{AP}$$

Wing Slot Seal

$$Wt_{41} = 5.84 L_{WS}$$

Where:

$$L_{WS} = \text{Wing slot seal length} - \text{ft}/\text{AP}$$

Wing Glove

$$Wt_{42} = 3.50 S_{GL}$$

Where:

$$S_{GL} = \text{Wing glove area} - \text{ft}^2/\text{AP}$$

Windshield Fairing

$$Wt_{13} = 1.5 S_{FW}$$

Where:

$$S_{FW} = \text{Windshield fairing area} - \text{ft}^2/\text{AP}$$

Body Configuration Penalties

$$Wt_{14} = \text{Body}$$

Where:

Body - Sum of configuration penalties weight (Ref: below)

1. Noise - boundary layer and engine blast impingement
2. Temperature - aerodynamic heat and engine blast impingement
3. Fatigue - service life
4. Aeroelastic considerations
5. Special and advanced materials
6. Unusual structural arrangements
7. Specific considerations due to configuration requirements - fail safe - safe life - safety - high altitude decompression effect on passengers, etc.
8. Miscellaneous

Fuselage Miscellaneous Weight

This weight item is a correction factor based on a statistical prediction error minimization study. This correction may be positive, zero, or negative.

USAF Fighters

$$Wt_{45} = 354.4 + 2.578 \left[\left(\frac{L_{FL} + L_{AL}}{D_{FF} + D_{AF}} \right) S_f N W_{DES} \times 10^{-7} \right]$$

Where:

S_f - Fuselage aerodynamic wetted area (total) - ft²

L_{FL} - Forward longeron length - ft

L_{AL} - Aft longeron length - ft

D_{FF} - Forward fuselage average effective bending depth - ft

D_{AF} - Aft fuselage average effective bending depth - ft

N - Flight design load factor (ultimate)

W_{DES} - Flight design gross weight - lbs

USN Fighters

$$Wt_{45} = 1.0788 \left[\left(\frac{L_{FL} + L_{AL}}{D_{FF} + D_{AF}} \right) S_f N W_{DES} \times 10^{-7} \right] - 11.08$$

Where:

S_f - Fuselage aerodynamic wetted area (total) - ft²

L_{AL} - Aft longeron length - ft

L_{FL} - Forward longeron length - ft

D_{FF} - Forward fuselage average effective bending depth - ft

D_{AF} - Aft fuselage average effective bending depth - ft

N - Flight design load factor (ultimate)

W_{DES} - Flight design gross weight -lbs.

Bombers

$$Wt_{45} = 1.39 \left(\sum_{i=1}^{44} Wt_i \right)^{0.9663} - \sum_{i=1}^{44} Wt_i$$

Transports

$$Wt_{45} = 0.789 \left(\sum_{i=1}^{44} Wt_i \right)^{1.027} - \sum_{i=1}^{44} Wt_i$$

Total Body Weight

$$T_B = \sum_{i=1}^{45} Wt_i + TK_i$$

2.4.2 LANDING GEAR EQUATIONS. The equations and definition of terms associated with the landing gear group weights are documented in the following paragraphs and References 1 and 3.

Main Landing Gear Structure

Single Wheel-Vertical Column-Land Based

$$Wt_{51} = .36 N_{ST} \left[W_{MAX} N_T \text{ or } W_L N_L \times 10^{-4} \right]^{.619} \left[\frac{(R_B)(L_{EX} + .30L_{TR})}{N_{ST}} \right]^{.591}$$

Where:

N_{ST} - Number of main landing gear struts/AP

W_{MAX} - Maximum gross wt. - lbs.

N_T - Taxi load factor (ultimate)

W_L - Landing design gross wt. - lbs.

N_L - Landing load factor (ultimate)

Where:

R_B - Drag brace ratio

$$= \frac{L_C}{L_C + L_B} \quad (\text{Taxi Condition})$$

$$\frac{L_{EX} - 1/2 (S_M)}{L_{EX} + L_B - 1/2 (S_M)} \quad \text{Landing Condition}$$

L_C - Compressed length - ϕ_L Trunnion to ϕ_L axle - in.

L_B - Brace length - ϕ_L Trunnion to drag brace fitting - in.

L_{EX} - Extended length - ϕ_L Trunnion to ϕ_L axle - in.

L_{TR} - Strut length above Trunnion - in.

S_M - Main landing gear stroke - in.

Main Landing Gear Structure

Single Wheel-Vertical Column-Carrier Based

$$Wt_{52} = 11.75 (N_{ST})^{.435} \left[W_L N_L \times 10^{-4} \right]^{.45} \left[R_B (L_{EX} + .30L_{TR}) \right]^{.565}$$

Where:

N_{ST} - Number of main landing gear struts/AP

W_L - Landing design gross wt. -lbs

N_L - Landing load factor (ultimate)

R_B - Drag brace ratio

$$= \frac{L_{EX} + 1/2 (S_M)}{L_{EX} + L_B + 1/2 (S_M)} \quad (\text{Landing Condition})$$

L_{EX} - Extended length - ϕ_1 Trunnion to ϕ_2 axle - in.

S_M - Main landing gear strokes - in.

L_B - Brace length - ϕ_1 Trunnion to drag brace fitting - in.

L_{TR} - Strut length above Trunnion - in.

Main Landing Gear Structure

Multi-Wheel-Vertical Column-Land Based

$$W_{L53} = .303 (N_{ST}) \left[\frac{W_{MAX} N_T R_B (L_{EX} + .30 L_{TR}) K_{MA} \times 10^{-3}}{N_{ST}} \right] .884$$

Where:

N_{ST} - Number of main landing gear struts/AP

W_{MAX} - Maximum gross wt. -lbs.

N_T - Taxi load factor (ultimate)

R_B - Drag brace ratio

$$= \frac{L_C}{L_C + L_B} \quad (\text{Taxi Condition})$$

L_{EX} - Extended length - ϕ_1 Trunnion to ϕ_2 axle - in.

L_{TR} - Strut length above Trunnion - in.

K_{MA} - Structural type factor

- 1.0 for Civil and military transports

- .733 for bombers (conventional)

- .476 for bombers (B-58 design)

L_C - Compressed length - ϕ_1 Trunnion to ϕ_2 axle - in.

L_B - Brace length - ϕ_1 Trunnion to drag brace fitting - in.

Main Landing Gear Structure

Single Wheel-Tripod Type-Land Based

$$W_{54} = .624 N_{ST} \left[W_{MAX} N_T \text{ or } W_L N_L \times 10^{-4} \right] \left[\frac{R_B (L_{EX} + .30L_{TR})}{N_{ST}} \right]^{.962}$$

Where:

N_{ST} - Number of main landing gear struts/AP

W_{MAX} - Maximum gross wt. -lbs.

N_T - Taxi load factor (ultimate)

W_L - Landing design gross wt. - lbs.

N_L - Landing load factor (ultimate)

R_B - Drag brace ratio

$$= \frac{L_C}{L_C + L_B} \quad (\text{Taxi Condition})$$

$$= \frac{L_{EX} + 1/2 S_M}{L_{EX} + L_B + 1/2 S_M} \quad (\text{Landing Condition})$$

L_{EX} - Extended length - ϕ_L Trunnion to ϕ_L axle - in.

L_B - Brace length - ϕ_L Trunnion to drag brace fitting - in.

L_C - Compressed length - ϕ_L Trunnion to ϕ_L axle - in.

L_{TR} - Strut length above Trunnion - in.

Main Landing Gear Structure

Single Wheel Tripod Type-Carrier Based

$$W_{55} = 1.375 N_{ST} \left[W_{MAX} N_T \text{ or } W_L N_L \times 10^{-4} \right]^{.768} \\ \left[\frac{R_B (L_{EX} + .3L_{TR})}{N_{ST}} \right]^{.962}$$

Where:

N_{ST} - Number of main landing gear struts/AP

W_{MAX} - Maximum gross wt. - lbs.

N_T - Taxi load factor (ultimate)

W_L - Landing design gross wt. - lbs

N_L - Landing load factor (ultimate)

R_B - Drag brace ratio

$$= \frac{L_C}{L_C + L_B} \quad (\text{Taxi Condition})$$

$$= \frac{L_{EX} + 1/2 S_M}{L_{EX} + L_B + 1/2 S_M} \quad (\text{Landing Condition})$$

L_{EX} - Extended length - \mathcal{C}_L Trunnion to \mathcal{C}_L axle - in.

L_B - Brace length - \mathcal{C}_L Trunnion to drag brace fitting - in.

L_C - Compressed length - \mathcal{C}_L Trunnion to \mathcal{C}_L axle - in.

L_{TR} - Strut length above Trunnion - in.

Nose Landing Gear

Bombers and Fighters - Land Based

$$W_{t56} = .701 \left[W_{MAX} N_T \text{ or } W_L N_L \times 10^{-4} \right]^{.595} \left[L_{EX} K_{NO} \right]^{.904}$$

Where:

W_{MAX} - Maximum gross wt. -lbs.

N_T - Taxi load factor (ultimate)

W_L - Landing design gross wt. - lbs.

N_L - Landing load factor (ultimate)

L_{EX} - Extended length - ϕ_L Trunnion to ϕ_L axle - in.

K_{NO} - Nose landing gear design criteria factor
- 1.0 (Conventional design)
- .47 (B-58 Design)

Nose Landing Gear

Transports - Land Based

$$W_{t57} = .153 \left[W_{MAX} N_T \text{ or } W_L N_L \times 10^{-4} \right]^{.772} \left[L_{EX} K_{NO} \right]^{1.173}$$

Where:

W_{MAX} - Maximum gross wt. -lbs.

N_T - Taxi load factor (ultimate)

W_L - Landing design gross wt-lbs.

N_L - Landing load factor (ultimate)

L_{EX} - Extended length - ϕ_L Trunnion to ϕ_L axle - in.

K_{NO} - Nose landing gear design criteria factor
- 1.0 (Conventional Design)
- .47 (B-58 Design)

Nose Land Gear

Fighters and Attack - Carrier Based - Fuselage Tow

$$Wt_{59} = 8.13 W_L N_L \times 10^{-4} L_{EX}^{.380} (L_{EX})^{.486}$$

Where:

W_L - Landing design gross wt. -lbs.

N_L - Landing load factor (ultimate)

L_{EX} - Extended length - ϕ_L Trunnion to ϕ_L axle - in.

Nose Landing Gear

Fighters and Attack - Carrier Based - Nose Landing Gear Tow

$$Wt_{59} = 3.77 W_c N_X L_{EX} \times 10^{-3} L_{EX}^{.486}$$

Where:

W_c - Catapult design gross wt. lbs.

N_X - Catapult load factor (ultimate)

L_{EX} - Extended length - ϕ_L Trunnion to ϕ_L axle - in.

Main Landing Gear Rolling Stock

Wheels - Land Based High Pressure

$$Wt_{60} = 14.03 (N_{WH})^{.406} \left[W_{MAX} N_T \text{ or } W_L N_L \times 10^{-4} \right]^{.619} \left[D_{WH} W_{FL} \times 10^{-2} \right]^{.594}$$

Where:

N_{WH} - Number main landing gear wheels per airplane

W_{MAX} - Maximum gross wt. - lbs

N_T - Taxi load factor (ultimate)

W_L - Landing design gross wt - lbs.

N_L - Landing load factor (ultimate)

D_{WH} - Wheel bead ledge dia. in.

W_{FL} - Wheel width between flanges - in.

Wheels - Land Based Low Pressure

$$Wt_{61} = 2.0 Wt_{60}$$

Wheels - Carrier Based

$$Wt_{62} = 19.01 (N_{WH})^{.475} \left[W_L N_L \times 10^{-4} \right]^{.419} \left[D_{WH} W_{FL} \times 10^{-2} \right]^{.525}$$

Where:

N_{WH} - Number main landing gear wheels per airplane

W_L - Landing design gross wt. - lbs.

N_L - Landing load factor (ultimate)

D_{WH} - Wheel bead ledge dia. - in.

W_{FL} - Wheel width between flanges - in.

Brakes - No Drag Chute

$$Wt_{63} = 16.10 (K.E. \times 10^{-6})^{.8752}$$

Where:

$$K.E. = \frac{(W_{MAX})}{64.4} (V_S)^2$$

V_S - Landing configuration power off stall speed - ft/sec

(a) T.O. gross for land based aircraft

(a) Design landing weight for carrier based aircraft

W_{MAX} - Maximum gross weight - lbs.

Brakes - With Drag Chute

$$Wt_{64} = 10.46 (K.E. \times 10^{-6})^{.8118}$$

Where:

$$K.E. = \frac{(W_{MAX})}{64.4} (V_S)^2$$

V_S - Landing configuration power off stall speed - ft/sec

@ T.O. gross for land based aircraft

@ Design landing weight for carrier based aircraft

W_{MAX} - Maximum gross weight - lbs

Tires (MIG)

1. If tire size has been determined select tire weight from manufacturer's handbook for maximum static load rating.
2. If tire selected is not standard use:

Type III and VII

$$Wt_{65} = 2.05 N_{TI} (D_t + D_{WH})^{.960} (W_{TI} + D_t - D_{WH})^{.864} (F_t)^{.384} \times 10^{-3}$$

Type VIII

$$Wt_{66} = 1.98 N_{TI} (D_t + D_{WH})^{1.170} (W_{TI} + D_t - D_{WH})^{1.053} (F_t)^{.468} \times 10^{-4}$$

Where:

D_t - Max. outside diameter - in.

D_{WH} - Bead ledge diameter - in.

W_{TI} - Max. section width - in.

F_T - Max. static load - lbs/tire

N_{TI} - Number main landing gear tires per airplane

Nose Landing Gear Rolling Stock

Nose Landing Gear, Tires, Tubes and Wheels

$$W_{t67} = \frac{.815 \sum_{i=51}^{66} W_{ti} - W_{t63} - W_{t64}}{(W_{MAX} \times 10^{-3}) \cdot .365}$$

Where:

W_{MAX} - Maximum weight lbs

Landing Gear Controls

$$W_{t68} = 0.423 \left(\sum_{i=51}^{67} W_{ti} \right)^{0.84}$$

Total Landing Gear Weight

$$W_{t69} = \sum_{i=51}^{68} W_{ti} + T_{IRWT} + F_{FIXED} + T_{AILB}$$

Where:

T_{IRWT} - Input tire weight

F_{FIXED} - Fixed weight input

T_{AILB} - Tail bumper weight

2.4.3 NACELLE EQUATIONS. The equations and definition of terms associated with the external nacelle group weights are documented in the following paragraphs and Reference 1.

Nacelles

Cowling

$$Wt_{80} = 35.45 N_N \left[K_N W_{NC} S_N \frac{B_N}{D_N} \text{ or } \frac{D_N}{B_N} \times 10^{-4} \right] .59$$

Where:

- N_N - Number of like nacelles per airplane
- K_N - Nacelle type constant
- 1.00 - Single subsonic - turbojet
 - 2.15 - Single supersonic - turbojet
 - 2.33 - Single supersonic - turbofan
 - .32 - Siamese subsonic - turbojet
 - 1.00 - Siamese subsonic - turbofan
 - .69 - Siamese subsonic - turbojet with outrigger gear
- W_{NC} - Wt. nacelle content (excluding nacelle structure) - lbs/nac
- S_N - Nacelle cowl surface area - ft²/nac
- B_N - Maximum nacelle breadth - ft.
- D_N - Maximum nacelle depth - ft.
- Use $\frac{B_N}{D_N}$ or $\frac{D_N}{B_N}$, whichever is greater

Pylons

Single Engine Installation

$$Wt_{81} = 24.11 N_{PYL} \left[\frac{K_{PYL} N W_{NC} L_N D_N \times 10^{-6}}{\cos \Lambda_{PYL}} \right]^{.952} (S_{PYL})^{.381}$$

Where:

N_{PYL} - Number of like pylons per airplane

K_{PYL} - 1.0 Military transports and bombers

- 1.46 Commercial transports

N - Flight design load factor (ultimate)

W_{NC} - Wt. nacelle contents (excluding nacelle structure) - lbs/nacelle

L_N - Nacelle cowl length - ft.

D_N - Nacelle cow maximum depth - ft.

Λ_{PYL} - Pylon leading edge sweep angle - degrees

S_{PYL} - Pylon planform area - ft²/nacelle

Siamese Engine Installations

$$Wt_{82} = 340.26 N_{PYL} \left[\frac{K_G N W_{NC} S_{PYL} \times 10^{-6}}{\cos \Lambda_{PYL}} \right]^{.693}$$

Where:

N_{PYL} - Number of like pylons per airplane

K_G - 1.0 No gear in nacelle

- 1.265 gear in nacelle

N - Flight design load factor (ultimate)

W_{NC} - Wt. nacelle contents (excluding nacelle structure) - lbs/nacelle

S_{PYL} - Pylon planform area - ft²/nacelle

Λ_{PYL} - Pylon leading edge sweep angle - degrees (See Figure 10)

N_{PYL} - Number of like pylons per airplane

Turboprop

Cowling

$$Wt_{83} = 11.81 N_N \left[W_{NC} S_N \frac{B_N}{D_N} \text{ or } \frac{D_N}{B_N} \times 10^{-3} \right]^{.593}$$

Where:

N_N - Number of like nacelles per airplane

W_{NC} - Wt. nacelle contents (excluding nacelle structure - (including propellers) - lbs/nacelle

S_N - Nacelle cowl surface area - ft²/nacelle

B_N - Maximum nacelle breadth - ft.

D_N - Maximum nacelle depth - ft.

Use B_N/D_N or D_N/B_N , whichever is greater.

Main Landing Gear Doors

$$Wt_{84} = .1611 (N_G) (S_{MD}/2)^{2.05}$$

Where:

N_G - Number of main landing gear installations per airplane

S_{MD} - Main landing gear door area - ft²/AP

Nacelles with Cowl Flaps

$$Wt_{85} = 35.97 N_N \left[W_{NC} S_N \frac{B_N}{D_N} \text{ or } \frac{D_N}{B_N} \times 10^{-3} \right]^{.465}$$

Where:

N_N - Number of like nacelles per airplane

W_{NC} - Wt. nacelle contents (excluding nacelle structure - (including propellers) - lbs/nacelle

S_N - Nacelle cowl surface area - ft²/nacelle

B_N - Maximum nacelle breadth - ft

D_N - Maximum nacelle depth - ft

Use $\frac{B_N}{D_N}$ or $\frac{D_N}{B_N}$, whichever is greater

Nacelles with Air Plugs, Baffles, etc.

$$Wt_{86} = 45.63 N_N \left[W_{NC} S_N \frac{B_N}{D_N} \text{ or } \frac{D_N}{B_N} \times 10^{-3} \right]^{.382}$$

Where:

N_N - Number of like nacelles per airplane

W_{NC} - Wt. nacelle contents (excluding nacelle structure - (including propellers) - lbs/nacelle

S_N - Nacelle cowl surface area - ft²/nacelle

B_N - Maximum nacelle breadth - ft.

D_N - Maximum nacelle depth - ft.

Use $\frac{B_N}{D_N}$ or $\frac{D_N}{B_N}$, whichever is greater

Main Landing Gear Doors

$$Wt_{87} = .1611 N_G (S_{MD}/2)^{2.05}$$

Where:

S_{MD} - Main landing gear door area - ft²/AP

N_G - Number main landing gear installations per airplane

Nacelles Total Weight

$$T_N = \sum_{i=80}^{87} W_{t_i} T_{K_i}$$

2.4.4 SUPPORT EQUATIONS. The equations and definition of terms associated with the support equations are documented in the following paragraphs and Reference 1. The support equations are optional equations used to obtain preliminary estimates of loads, etc.

Support Equation

Fun Tail Load (Ultimate)

$$F_V = 1583.1 (N W_{DES} \times 10^{-4})^{.891}$$

Where:

N = Ultimate design load factor

W_{DES} = Design gross weight

Horizontal Tail Load (ultimate)

$$F_H = 95.39N \left[\frac{W_{DES}}{\left(\frac{l_{TH}}{\bar{C}_W} \frac{S_{HT}}{S_W} \right)^{.40}} \times 10^{-3} \right]^{1.008}$$

W_{DES} = Design gross weight - lbs

\bar{C}_W = Wing mean aerodynamic chord - ft.

l_{TH} = Horiz. tail length - .25 MAC wing to .25 MAC Horiz. tail - ft.

S_{HT} = Horizontal tail area - ft²/AP

S_W = Gross wing area - ft²

Landing Configuration Power Off Stall Speed at Design Landing Weight

$$V_S = \left(\frac{W_{MAX}}{0.001189 S_W C_{L_i}} \right)^{0.5}$$

Where:

W_{MAX} - Max gross weight - lbs

S_W - Wing area - ft²

C_{L_i} - Landing configuration C_L

Ultimate Duct Pressure - lbs/in²

$$P_D = .134 (q)^{1.985}$$

Where: q is based on V_H

Arresting Hook Drag Component - Ult. - lbs.

$$D_c = 1460 \left[W_L (V_S)^2 \times 10^{-6} \right]^{.71}$$

W_L - Design landing weight - lbs

V_S - Landing configuration power-off stall speed at design landing weight - ft/sec

Nose Landing Gear Maximum Vertical Reaction - lbs (Ultimate)

Land Based

$$F_{VN} = 4226.8 (W_{MAX} N_T \text{ or } W_L N_L \times 10^{-4})^{.658}$$

Note: Use $W_{MAX} N_T$ or $W_L N_L$, whichever is greater

Carrier Based

$$F_{VN} = 4859.6 (W_L N_L \times 10^{-4})^{.782}$$

Where:

W_{MAX} - Maximum gross weight - lbs

W_L - Design landing weight - lbs

N_T - Taxi load factor (ultimate)

N_L - Design landing factor (ultimate)

Main Landing Gear Maximum Vertical Reaction -lbs (Ultimate)

Land Based

$$F_{VM}/\text{Side} = 3855.7 (W_{MAX} N_T \text{ or } W_L N_L \times 10^{-4})^{1.04}$$

Note: Use $W_{MAX} N_T$ or $W_L N_L$, whichever is greater

Carrier Based

$$F_{VM}/\text{Side} = 8648.9 (W_L N_L \times 10^{-4})^{.797}$$

Where:

W_{MAX} - Maximum gross weight - lbs.

W_L - Design landing weight - lbs

N_T - Ultimate taxi load factor

N_L - Design landing factor (ultimate)

SECTION 3

COMPUTER PROGRAM DISCUSSION

3.1 PROGRAM DISCUSSION

This program consists primarily of empirical equations defined in paragraph 2.4.1 through 2.4.4 and Reference 1.

The program is structured so the user can go through and use every equation and then with a tailoring constant (TK(I)) zero out the equations that are not applicable to his vehicle definition. This tailoring constant can also be used to tailor weights up and down as a function of exotic material utilizations, design concepts and particular configuration penalties.

The program contains nine subroutines and a driver program. It is written in Fortran IV and can be easily adapted for use on a small computer. The deck setup for CYBER 70 Model 72-16 is presented in Figure 1.

3.1.1 DESCRIPTION OF SUBROUTINES. This section describes each individual subroutine to further represent the internal structure of the program.

3.1.1.1 Driver Program BLN. The flow chart presented in Figure 2 represents the various subroutine modules and general program flow of the driver program.

3.1.1.2 Subroutine PRESET. The purpose of this subroutine is to preset the input values and weights to zero and to establish a number for the input and output devices.

3.1.1.3 Subroutine IDATA. The purpose of this subroutine is to input data by means of a name list device.

3.1.1.4 Subroutine BWT. This is the body empirical weight prediction subroutine utilizing empirical equations defined in paragraph 2.4.1 and Reference 1.

3.1.1.5 Subroutine WTSUM. This is the body semi-analytical weight prediction subroutine utilizing the input weight for the basic shell in Reference 2 and the empirical weight penalties computed in the BWT subroutine. It also distributes empirical weight penalties into panels, longerons, frames, webs, and non-structure by percentages as shown in Table 1. The following procedure illustrates the method used to change the percentage of Wing Reaction Body Tie penalty distribution in Frames from 40 to 35

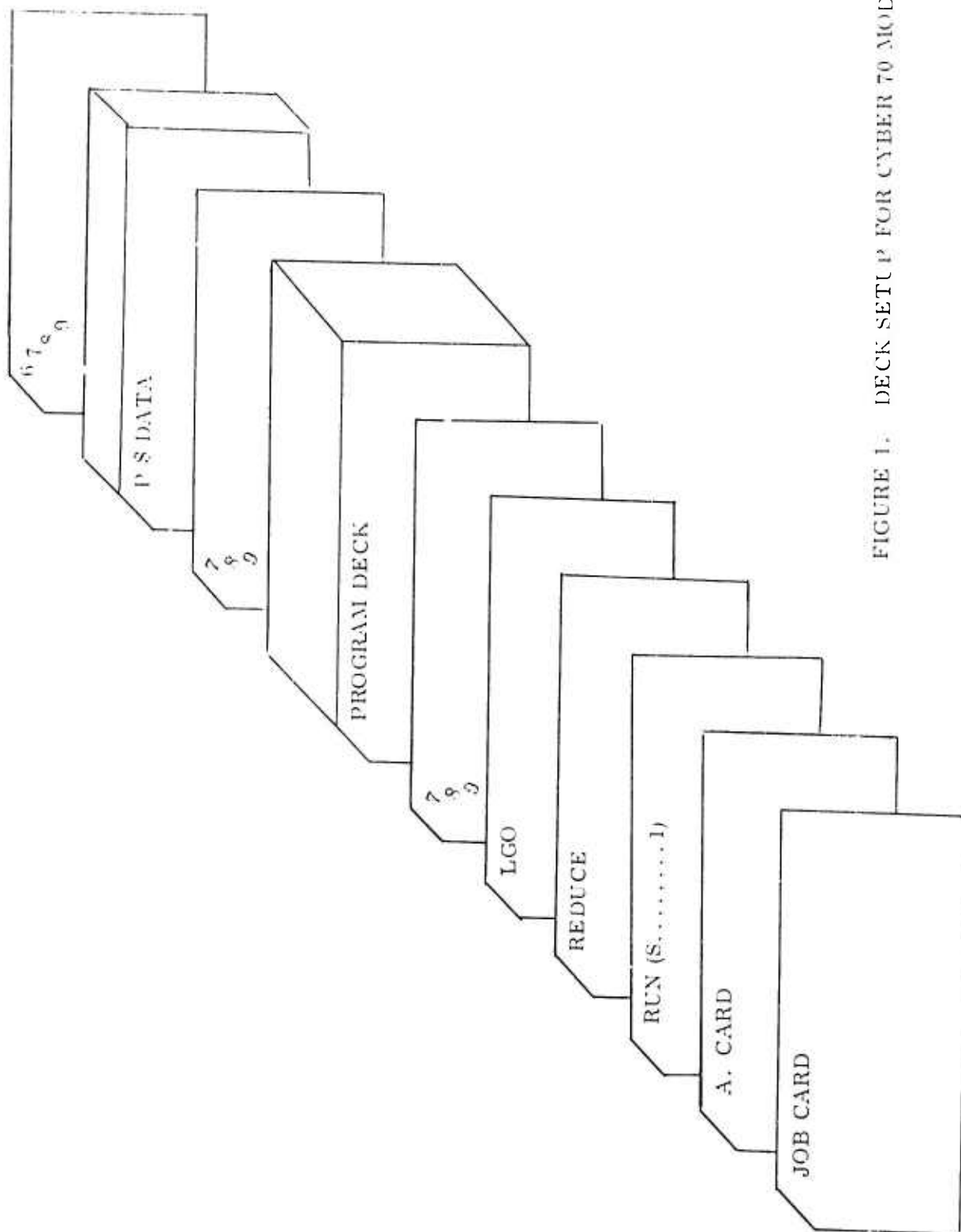


FIGURE 1. DECK SETUP FOR CYBER 70 MODEL 72-16

percent and in Longerons from 10 to 15%. Locate the column number for Longeron (2) and Frames (3) and the Row number for Wing Reaction Body Tie (5) and input PCW (2,5) = 0.15 and PCW (3,5) = 0.35 (reference example bottom of Table 1). All percentage references in the table can be changed by the input variable PCW (I,J) where I = column number and J = row number.

3.1.1.6 Subroutine BODYO. This subroutine outputs the body weights.

3.1.1.7 Subroutine LGWT. This is the landing gear empirical weight prediction subroutine utilizing the empirical equations defined in paragraph 2.4.2 and Reference 1.

3.1.1.8 Subroutine LGOP. This is the landing gear output subroutine.

3.1.1.9 Subroutine NAC. This is the nacelle empirical weight prediction subroutine utilizing the empirical equations defined in paragraph 2.4.3 and Reference 1.

3.1.1.10 Subroutine NACOP. This subroutine outputs the nacelle weights.

3.2 PROGRAM INPUT

The input to this program is read through the namelist library subroutine. The namelist input deck consists of one card for each input variable. Each input card has on it the Fortran name, the present value of the variable, and a brief definition of the variable. All input variables are initialized to zero. On multiple runs, every variable that is not used on the second run that was used on the first run and all support variables must be input as zero.

All variables that are support variables that do not have a known value, must be input as zero. If the support variable input is zero, the program will use equations in paragraph 2.4.4 to calculate the value.

The input card is automatically printed back in the output. A list of all possible input variables and their definitions is presented in Appendix II.

The variable FLAG is the only control variable in this program and its function is illustrated in Figure 2.

3.3 PROGRAM OUTPUT

This program was developed to print out the answer to every equation, even if the answer is zero, in order to verify if all equations intended have been applied.

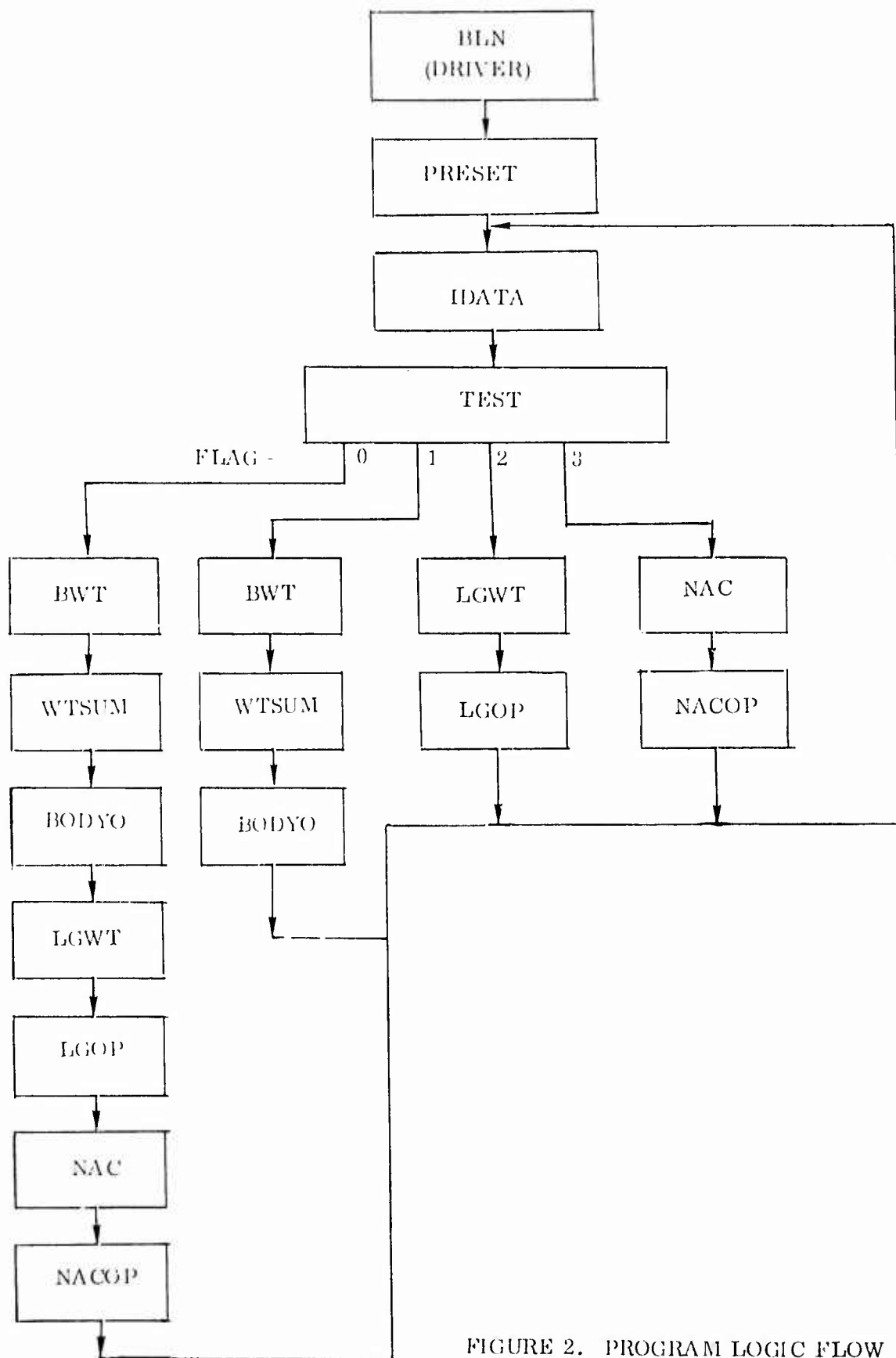


FIGURE 2. PROGRAM LOGIC FLOW

The output includes a print-back of the input.

Fuselage Output

The fuselage weight is output in seven columns. The first column presents the pure empirical weights. These weights subtotal at the bottom of the column for total empirical weight. The next five columns are the printout of the semi-analytical weights. The top line of numbers are input from APAS and are analytical weights. The remaining columns show the weight of penalty per item (Table 1) (Panels, Longerons, Frames, Webs, Non-Struc) and are empirical weights. The remaining column is the horizontal sub-total of the semi-analytical rows. The bottom line presents the sub-totals of semi-analytical columns and in the last column the total semi-analytical weight. The remaining four items present the actual body weight and body predicted weight, as well as the two weight factors (body actual weight divided by semi-analytical weight and body actual weight divided by empirical weight).

Landing Gear Output

The landing gear weight output is all empirical, except for the tires and tail bumper weights. The tire weight can be empirical or input. The tail bumper weight must be input.

This section also outputs the Landing Configuration Power Off Stall Speed, Design Load, Drag Brace Ratio, and Kinetic Energy.

Nacelle Output

The nacelle weight output is all empirical weights. The actual weight is presented along with the weight factor.

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the conclusions reached as a result of this development effort. Recommendations are made for future extensions and refinements of the computer program developed on this study.

Conclusions:

A computer program to estimate body, landing gear, and nacelle weights was successfully developed. The results of the test study effort have been favorably correlated with aircraft data in three test cases.

Recommendations:

- a) The program should be expanded to include wings, tails and subsystem weight subroutines.
- b) The math model and program should be expanded to include geometry calculations.
- c) The math model and program should be expanded to include exotic materials and composites.

SECTION 5

REFERENCES

1. "Aircraft Structural Weight Estimating Methods," Convair Aerospace Report ERR-FW-242, September 1964.
2. Kruse, G.S., Peterson, L.M. "Automated Structural Sizing Techniques For Aircraft and Vehicle Structures," GDCA-ERR-1748, December 1972.
3. Caddell, W. E. Generalized Weight Estimating Methods for Aircraft Structures and Equipment. Convair Aerospace Report GEC-ERR-FW-039, 1960.

APPENDIX I
Program Listing

GO TO 30
END

A 720
A 730-

```

SUBROUTINE PRESET
COMMON /INP/ P(699)
COMMON /HEIGHT/ WT(100)
COMMON /IO/ M,J
J=5
M=6
DO 20 I=1,699
20 P(I)=0.0
DO 30 I=1,100
30 WT(I)=0.0
C
RETURN
END

```

```

9 10
9 20
9 30
9 40
9 50
9 60
9 70
9 80
9 90
9 100
9 110
9 120
9 130-

```


C 396
C 400
C 410-

C 20 FORMAT (1H1)
END

C	IF (DWF.NE.0.0) WT(10)=10.9*FV*FL*LV/10.**6/DWF	D1530
C	AFT SIDE BENDING	D1540
C		D1550
C		D1560
C		D1570
C	IF (JWA.NE.0.0) WT(11)=25.9*FV*LV**2/10.**6/DWA	D1580
C	FWD FUEL INERTIA	D1590
C		D1600
C		D1610
C	IF (DFF.NE.0.0) WT(12)=25.9*WFF*ULF*LV**2/10.**6/DFF	D1620
C	AFT FUEL INERTIA	D1630
C		D1640
C		D1650
C	IF (DAF.NE.0.0) WT(13)=25.9*WFA*ULF*LAF**2/10.**6/DAF	D1660
C	AFT ENGINE BENDING	D1670
C		D1680
C		D1690
C	IF (DAF.NE.0.0) WT(14)=25.9*WPP*ULF*LV**2/10.**6/DAF	D1700
C	AFT HORIZ. TAIL BENDING	D1710
C		G1720
C		D1730
C	IF (DAF.NE.0.0) WT(15)=25.9*FH*LHT**2/10.**6/DAF	D1740
C	FUEL PROVISIONS	D1750
C		D1760
C		D1770
C	WT(16)=KF*GF**J.75*VF**J.375	D1780
C	ARRESTING GEAR PROVISIONS	D1790
C		D1800
C		D1810
C	WT(17)=.46*DC/1000.	D1820
C	CATAPULT/HOLDBACK FUS TOW	D1830
C		D1840
C		D1850
C	WT(18)=.192*NX*WC/1000.	D1860
C	CATAPULT/HOLDBACK NLG TOW	D1870
C		D1880
C		D1890
C	IF ((WLAND*DFF*WC*NX).NE.0.0) WT(19)=0.30*(WC/WLAND)**4.09*LEXN**2	D1900

1/DFE*WC*NX/10.0**6	D1910
ENGINE PROVISIONS	D1920
WT(20)=3.85*(TPE/1000.)*.6*NE+3.24*(LF*DE*NE)**.9	D1930
DUCT PROVISIONS	D1940
WT(21)=.044*ND*LD*((CI+CE)/2.)*.1.3*PD**.6	D1950
MLG DOORS	D1960
WT(22)=K*LD*SM*.1.125	D1970
MLG CUTOUT/LOAD INTROD	D1980
IF (SM.NE.0.0) AT(23)=.385*(FV*LEX/1000.)*.9*NST/SM	D1990
EXTERNAL STORES PROV	D2000
WT(24)=(.067+TYPE*.333)*(WS*.7*NS+WS1**.7*NS1+WS2**.7*NS2)	D2010
SPEED BRAKES	D2020
WT(25)=1.923*(NS3*SS3)**0.96*(C*CD*SSR/1000.)*.0.49	D2030
80MB/MISSILE RAY CUTOUT	D2040
WT(26)=K3*ULF**.37*(WWE*LM3*OMB/1000.)*.494	D2050
8/M BAY DOORS+MECH CONVENT	D2060
WT(27)=5.65*(SM3*LM3)**.483*ULF**.12*(Q/100.)*.241	D2070
8/M BAY DOORS+MECH ROTARY	D2080
WT(28)=.863*(SM3*LM3)**.758*ULF**.19*(Q/100.)*.38	D2090
	D2100
	D2110
	D2120
	D2130
	D2140
	D2150
	D2160
	D2170
	D2180
	D2190
	D2200
	D2210
	D2220
	D2230
	D2240
	D2250
	D2260
	D2270
	D2280

CABIN FLOORING+SUPPORT TRN	02290
WT(29)=6.51*(ULF*WF*AF/1000.)*.924	02300
CABIN WINDOWS TRANSPORTS	02310
WT(31)=10.0*AGL	02320
PRESSURE WFB+SEALANT TRN	02330
WT(31)=12.57*SWP*PC/1000.	02340
AIR EXTRACTION PROV TRN	02350
WT(32)=2+.65*LFLR	02360
CARGO LOADING RAMP+ACC TRN	02370
WT(33)=1.85*(SRA*LRA*WF/100.)*.785	02380
MLG EXTERNAL FAIRINGS	02390
WT(34)=.0403*SGF*LG*(0/100.)*.25	02400
SIDE LOADING DOOR+MECH	02410
WT(35)=9.0*SDA	02420
CLAMSHELL DOORS+MECH	02430
WT(36)=2.75*CSDA	02440
FLAT CARGO CLEARANCE	02450
WT(37)=9.0*FCCDA	02460
FUEL TANK FLOORING	02470
	02480
	02490
	02500
	02510
	02520
	02530
	02540
	02550
	02560
	02570
	02580
	02590
	02600
	02610
	02620
	02630
	02640
	02650
	02660

C	WT(38)=7.25*FTFA	D2670
C		D2680
C	SWING TAIL/NCSE PROVISIONS	D2690
C		D2700
C	WT(39)=63.5*CF	D2710
C		D2720
C	OVER WING FAIRING	D2730
C	WT(40)=1.95*SWF	D2740
C		D2750
C	WING SLOT SEAL	D2760
C		D2770
C	WT(41)=5.84*LWS	D2780
C		D2790
C	WING GLOVE	D2800
C		D2810
C	WT(42)=3.50*SGL	D2820
C		D2830
C	WINDSHIELD FAIRING AREA	D2840
C		D2850
C	WT(43)=1.5*SFW	D2860
C		D2870
C	BODY CONFIG. PENALTIES (MISC WT.)	D2880
C		D2890
C	WT(44)=BODY	D2900
C		D2910
C	FUSELAGE MISC WEIGHT(STATISTICAL CORRECTION)	D2920
C		D2930
C	IF (TYPE) 200,190,200	D2940
C	190 CONTINUE	D2950
C		D2960
C	IF ((OFF+DAF).NE.0.0) WT(+5)=354.4-2.578*(LFL+LAL)/(OFF+DAF)*SFF*U	D2970
C	1LF*WJES/10.**7	D2980
C	GO TO 260	D2990
C	200 CONTINUE	D3000
C	IF (TYPE-1.) 220,210,220	D3010
C	210 CONTINUE	D3020
C		D3030
C		D3040

```

C
      IF ((OFF+DAF).NE.0.0) WT(45)=1.3788*((LFL+LAL)/(OFF+DAF))*S' =*ULF*W
      1DES/10.**7)-11.38
      GO TO 260
220 CONTINUE
C
C
      AB=0.0
      DO 230 I=1,44
230 AB=AB+WT(I)*TK(I)
C
C
      IF (TYPE-2.) 253,240,250
240 CONTINUE
C
C
      WT(45)=1.39*AB**0.9663-AB
      GO TO 260
250 CONTINUE
C
C
      WT(45)=0.789*AB**1.027-AB
260 CONTINUE
C
C
      TAILOR WEIGHT WITH TK'S(TAILORING CONSTANTS)
C
C
      TB=0.0
      DO 270 I=1,45
      WT(I)=WT(I)*TK(I)
      INT=WT(I)+.5
      WT(I)=INT
270 TB=TB+WT(I)
C
      RETURN
C
      END
03050
03060
03070
03080
03090
03100
03110
03120
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03140
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C      SUBROUTINE WTSU4
C
C      BODY SIMIL-ANALYTICAL WEIGHT SUMMING ROUTINE
C
C      REAL IPWT,K,KB,KF,KG,KMA,KMLD,KN,KNO,KPYL,KS,LAF,LAL,LB,LD,LE,LESP
C      1YL,LEX,LEXN,LFF,LFL,LFLR,LGF,LHT,LMB,LN,LNX,LPP,LKA,LTR,LVT,LWS,XD
C      2,NF,JF,NG,NL,NY,NPYL,NS,NS1,NS2,NSB,NST,NT,NTI,NWH,NX
C
C      COMMON /INP/ TK(100),AF,AGL,RN,3DDY,3P,CJ,CF,CF,CI,CL,CSRA,DAF,DC,
C      1DCK,DE,DEF(6),DFF,DHB,DN,DT,DWA,DWF,DWH,FCCDA,FH,FIXED,FLAG,FTFA,F
C      2V,FVM,FVN,GF,HIVG,IPWT(3),K,KB,KF,KG,KMA,KMLD,KN,KNO,KPYL,KS,LAF,L
C      3AL,LB,LD,LE,LSPYL,LEX,LEXN,LFF,LFL,LFLR,LGF,LHT,LMB,LN,LNX,LPP,L
C      4A,LTR,LVT,LWS,XD,NF,NG,NL,NPYL,NS,NS1,NS2,NSB,NST,NT,NTI,NWH
C      5,NX,PC,PCW(5,45),PD,Q,SC,SDA,SFF,SFH,SGL,SM,SM8,SMD,SN,SND,SPY
C      6L,SRA,SSB,SW,SWF,SWP,TAIL9,TITLE(6),TIRWT,TPE,TYPE,ULF,VC,VVS,WAI,W
C      7C,WDES,WFW,WFA,WFF,WFL,WFI,WLAND,WMAX,WNC,WPP,WS,WS1,WS2,WTI,WTP(5,
C      845),WWE
C
C      COMMON /IO/ M,J
C
C      COMMON /WEIGHT/ WT(100)
C
C      COMMON /ROUT/ TB,WTG,WTV(5),WTH(45)
C
C      WTG=0.0
C      DO 20 I=1,5
C      20   WTV(I)=0.0
C      DO 30 II=1,45
C      30   WTH(II)=0.0
C      DO 40 III=1,45
C      40   IF (II.NE.1) WTP(I,III)=WT(III)*PCW(I,III)
C      WTH(III)=WTH(III)+WTP(I,III)
C      WTV(I)=WTV(I)+WTP(I,III)
C      40   WTG=WTG+WTP(I,III)

```

E 390
E 400
E 410-

RETURN
END

C

	TITLE	
WRRITE	(M,40)	F 390
WRRITE	(M,50)	F 400
WRRITE	(M,530)	F 410
WRRITE	(M,70)	F 420
WRRITE	WT(1),(WTP(II,1),II-1,5),WTH(1)	F 430
WRRITE	WT(2),(WTP(II,2),II=1,5),WTH(2)	F 440
WRRITE	WT(3),(WTP(II,3),II=1,5),WTH(3)	F 450
WRRITE	WT(4),(WTP(II,4),II=1,5),WTH(4)	F 460
WRRITE	WT(5),(WTP(II,5),II=1,5),WTH(5)	F 470
WRRITE	WT(6),(WTP(II,6),II=1,5),WTH(6)	F 480
WRRITE	WT(7),(WTP(II,7),II=1,5),WTH(7)	F 490
WRRITE	WT(8),(WTP(II,8),II=1,5),WTH(8)	F 500
WRRITE	WT(9),(WTP(II,9),II=1,5),WTH(9)	F 510
WRRITE	WT(10),(WTP(II,10),II=1,5),WTH(10)	F 520
WRRITE	WT(11),(WTP(II,11),II=1,5),WTH(11)	F 530
WRRITE	WT(12),(WTP(II,12),II=1,5),WTH(12)	F 540
WRRITE	WT(13),(WTP(II,13),II=1,5),WTH(13)	F 550
WRRITE	WT(14),(WTP(II,14),II=1,5),WTH(14)	F 560
WRRITE	WT(15),(WTP(II,15),II=1,5),WTH(15)	F 570
WRRITE	WT(16),(WTP(II,16),II=1,5),WTH(16)	F 580
WRRITE	WT(17),(WTP(II,17),II=1,5),WTH(17)	F 590
WRRITE	WT(18),(WTP(II,18),II=1,5),WTH(18)	F 600
WRRITE	WT(19),(WTP(II,19),II=1,5),WTH(19)	F 610
WRRITE	WT(20),(WTP(II,20),II=1,5),WTH(20)	F 620
WRRITE	WT(21),(WTP(II,21),II=1,5),WTH(21)	F 630
WRRITE	WT(22),(WTP(II,22),II=1,5),WTH(22)	F 640
WRRITE	WT(23),(WTP(II,23),II=1,5),WTH(23)	F 650
WRRITE	WT(24),(WTP(II,24),II=1,5),WTH(24)	F 660
WRRITE	WT(25),(WTP(II,25),II=1,5),WTH(25)	F 670
WRRITE	WT(26),(WTP(II,26),II=1,5),WTH(26)	F 680
WRRITE	WT(27),(WTP(II,27),II=1,5),WTH(27)	F 690
WRRITE	WT(28),(WTP(II,28),II=1,5),WTH(28)	F 700
WRRITE	WT(29),(WTP(II,29),II=1,5),WTH(29)	F 710
WRRITE	WT(30),(WTP(II,30),II=1,5),WTH(30)	F 720
WRRITE	WT(31),(WTP(II,31),II=1,5),WTH(31)	F 730
WRRITE	WT(32),(WTP(II,32),II=1,5),WTH(32)	F 740
WRRITE	WT(33),(WTP(II,33),II=1,5),WTH(33)	F 750
WRRITE	WT(34),(WTP(II,34),II=1,5),WTH(34)	F 760
WRRITE	WT(35),(WTP(II,35),II=1,5),WTH(35)	

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WRITE (M,420) WT(36), (WTP(II,36), II=1,5), WTH(36)
WRITE (M,430) WT(37), (WTP(II,37), II=1,5), WTH(37)
WRITE (M,440) WT(38), (WTP(II,38), II=1,5), WTH(38)
WRITE (M,450) WT(39), (WTP(II,39), II=1,5), WTH(39)
WRITE (M,460) WT(40), (WTP(II,40), II=1,5), WTH(40)
WRITE (M,470) WT(41), (WTP(II,41), II=1,5), WTH(41)
WRITE (M,480) WT(42), (WTP(II,42), II=1,5), WTH(42)
WRITE (M,490) WT(43), (WTP(II,43), II=1,5), WTH(43)
WRITE (M,500) WT(44), (WTP(II,44), II=1,5), WTH(44)
WRITE (M,510) WT(45), (WTP(II,45), II=1,5), WTH(45)
WRITE (M,520) T3, (WTV(II), II=1,5), WTG
WRITE (M,20) IPAT(1), WTG
WRITE (M,30) BNJF, BNOFA

RETURN

20 FORMAT (1X,34H BODY ACTUAL WEIGHT
1-PREDICTED WEIGHT F10.1)
30 FORMAT (1X,34H EMPIRICAL WEIGHT FACTOR
1-ANALYTICAL FACTOR F10.3)
40 FORMAT (//)
50 FORMAT (1X,13H BODY WEIGHT ,6A10//)
60 FORMAT (1H1)
70 FORMAT (1X,34H BASIC SHELL
80 FORMAT (1X,34H COCKPIT PROVISIONS
90 FORMAT (1X,34H VLG DOOR
100 FORMAT (1X,34H VLG CUTOFF / LOAD INTRODUCTION
110 FORMAT (1X,34H WING REACTION BODY TIE
120 FORMAT (1X,34H TAIL PROVISIONS
130 FORMAT (1X,34H WINGSHIELD AND CANOPY
140 FORMAT (1X,34H FWD VERTICAL INERTIA
150 FORMAT (1X,34H AFT VERTICAL INERTIA
160 FORMAT (1X,34H FWD SIDE BENDING
170 FORMAT (1X,34H AFT SIDE BENDING
180 FORMAT (1X,34H FWD FUEL INERTIA
190 FORMAT (1X,34H AFT FUEL INERTIA

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C C C C

230	FORMAT	(1X, 34H	AFT ENGINE BENDING	7F10.1)	F1150
240	FORMAT	(1X, 34H	AFT HORIZ TAIL BENDING	7F10.1)	F1160
250	FORMAT	(1X, 34H	FUEL PROVISIONS	7F10.1)	F1170
260	FORMAT	(1X, 34H	ARRESTING GEAR PROVISIONS	7F10.1)	F1180
270	FORMAT	(1X, 34H	CATAPULT/HOLD RACK FUS TOW	7F10.1)	F1190
280	FORMAT	(1X, 34H	CATAPULT/HOLD RACK NLG TOW	7F10.1)	F1200
290	FORMAT	(1X, 34H	ENGINE PROVISIONS	7F10.1)	F1210
300	FORMAT	(1X, 34H	DUCT PROVISIONS	7F10.1)	F1220
310	FORMAT	(1X, 34H	NLG DOORS	7F10.1)	F1230
320	FORMAT	(1X, 34H	NLG CUTOFF/LOAD INTRO	7F10.1)	F1240
330	FORMAT	(1X, 34H	EXTERNAL STORES PROV	7F10.1)	F1250
340	FORMAT	(1X, 34H	SPFED BRACKS	7F10.1)	F1260
350	FORMAT	(1X, 34H	30M3/MISSLE BAY CUTOFF	7F10.1)	F1270
360	FORMAT	(1X, 34H	3/M BAY DOORS+MECH CONVNT	7F10.1)	F1280
370	FORMAT	(1X, 34H	3/M BAY DOORS+MECH ROTARY	7F10.1)	F1290
380	FORMAT	(1X, 34H	CABIN FLOORING+SUPPORT TRN	7F10.1)	F1300
390	FORMAT	(1X, 34H	CABIN WINDOWS TRANSPORTS	7F10.1)	F1310
400	FORMAT	(1X, 34H	PRESSURE WEB+SEALANT TRN	7F10.1)	F1320
410	FORMAT	(1X, 34H	AIR EXTRACTION PROV TRN	7F10.1)	F1330
420	FORMAT	(1X, 34H	CARGO LOADING RAMP+ACC TRN	7F10.1)	F1340
430	FORMAT	(1X, 34H	NLG EXTERNAL FAIRINGS	7F10.1)	F1350
440	FORMAT	(1X, 34H	SIDE LOADING DOOR+MECH	7F10.1)	F1360
450	FORMAT	(1X, 34H	CLAMSHELL DOORS+MECH	7F10.1)	F1370
460	FORMAT	(1X, 34H	FLAT CARGO CLEARANCE DOORS	7F10.1)	F1380
470	FORMAT	(1X, 34H	FUEL TANK FLOORING	7F10.1)	F1390
480	FORMAT	(1X, 34H	SWING TAIL/NOSE PROVISIONS	7F10.1)	F1400
490	FORMAT	(1X, 34H	OVER WING FAIRING	7F10.1)	F1410
500	FORMAT	(1X, 34H	WING SLOT SEAL	7F10.1)	F1420
510	FORMAT	(1X, 34H	WING GLOVE	7F10.1)	F1430
520	FORMAT	(1X, 34H	WINDSHIELD FAIRING	7F10.1)	F1440
530	FORMAT	(1X, 34H	BODY CNFIG PENALTIES	7F10.1)	F1450
540	FORMAT	(1X, 34H	FUSELAGE MISC WEIGHT	7F10.1)	F1460
550	FORMAT	(1X, 34H	TOTAL BODY	7F10.1)	F1470
560	FORMAT	(1X, 46X,	10HPANELS 10HLONGERONS , 10HFRAMES , 10HWEBS		F1480
570	FORMAT	(1X, 46X,	12H HORZ-TOTALS/)		F1490
580	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		F1500-
590	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
600	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
610	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
620	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
630	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
640	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
650	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
660	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
670	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
680	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
690	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
700	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
710	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
720	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
730	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
740	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
750	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
760	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
770	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
780	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
790	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
800	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
810	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
820	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
830	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
840	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
850	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
860	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
870	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
880	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
890	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
900	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
910	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
920	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
930	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
940	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
950	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
960	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
970	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
980	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
990	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		
1000	FORMAT	(1X, 46X,	10HNON STRUC , 12H HORZ-TOTALS/)		


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C 390
C 400
C 410
C 420
C 430
C 440
C 450
C 460
C 470
C 480
C 490
C 500
C 510
C 520
C 530
C 540
C 550
C 560
C 570
C 580
C 590
C 600
C 610
C 620
C 630
C 640
C 650
C 660
C 670
C 680
C 690
C 700
C 710
C 720
C 730
C 740
C 750
C 760

WEIGHT PER TIRE
FT=0.0
IF (NTI.NE.0.0) FT=WMAX/NTI

DRAG GRADE RATIO

RR(1)=0.0
RR(2)=0.0
IF ((LC+LB).NE.J.0) RR(1)=LC/(LC+LB)
IF ((LEX+LB-C.5*SM).NE.J.0) RR(2)=(LEX-.5*SM)/(LEX+LB-.5*SM)

INTERMEDIATE CALCULATIONS

LEA=LEX+.3*LTR

MLG STRUC-SINGLE WHEEL-VEFT,COLUMN LAND BASED

DO 20 I=1,2
  AB(I)=0.0
  IF (NST.NE.0.0) AB(I)=8.36*NST*LOAD(I)**.619*(R3(I)*LEA/IST)**.591
20 CONTINUE

DESIGN LOAD TEST

IF (AB(1)-AB(2)) 40,40,30
30 WT(51)=AB(1)
50 TO 50
40 WT(51)=AB(2)
50 CONTINUE

MLG STRUC-SINGLE WHEEL-VEFT,COLUMN CAR BASED

WT(52)=11.75*NST**.435*LOAD(2)**.45*(R2(?)*LEA)**.565

MLG STRUC-MULTIE WHEEL-VEFT,COLUMN LAND BASED

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C      IF (NST.NE.0.0) WT(53)=.303*NST*((WMAX*NT*RB(1)*LEA*KMA/1000.)/NST
C      1)**.984
C
C      MLG STRUC-SINGLE WHEEL-TRIPOD TYPE LAND BASED
C
C      DO 50 I=1,2
C      AR(I)=0.0
C      IF (NST.NE.0.0) AB(I)=.624*NST*LOAD(I)*(RB(I)*LEA/NST)**.9=2
C      60 CONTINUE
C      IF (AB(1)-AB(2)) 80,80,70
C      70 WT(54)=AB(1)
C      80 TO 90
C      80 WT(54)=AB(2)
C      90 CONTINUE
C
C      MLG STRUC-SINGLE WHEEL-TRIPOD TYPE CARR BASED
C
C      DO 100 I=1,2
C      AB(I)=0.0
C      IF (NST.NE.0.0) AB(I)=1.375*NST*LOAD(I)**.769*(RB(I)*LEA/NST)**.36
C      120 CONTINUE
C      100 CONTINUE
C      IF (AB(1)-AB(2)) 120,120,110
C      110 WT(55)=AB(1)
C      120 TO 130
C      120 WT(55)=AB(2)
C      130 CONTINUE
C
C      IF ((WL*NL)-(WMAX*NT)) 150,140,140
C      140 CONTINUE
C
C      DLOAD=LOAD(2)*10000.
C      AR=RB(1)
C      150 TO 160
C      150 CONTINUE
C
C      DLOAD=LOAD(1)*10000.

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C      WT(62)=19.01*NW4**4.75*LOAD(2)**4.19*(DWH+WFL/100.))**.525
C      BRKES -NO DRAG CHUTE
C      WT(63)=16.10*(KE/10.**)6)**.8752
C      BRKES -   DRAG CHUTE
C      WT(64)=10.46*(KE/10.**)6)**.8118
C      IF ((WTI+DT).LE.DWH) GO TO 170
C      TIRES-TYPE III AND VII
C      WT(65)=2.05*NTI*(DT+DWH)**.960*(WTI+DT-DWH)**.864/1000.*FT**384
C      TIRES-TYPE VIII
C      WT(66)=1.98*NTI*(DT+DWH)**1.170*(WTI+DT-DWH)**1.053/10000.*FT**40
C      170 CONTINUE
C      DO 190 I=51,66
C      WT(I)=WT(I)*TK(I)
C      190 CONTINUE
C      NLG ROLLING STOCK
C      IF (WMAX.NE.C.0) WT(67)=.815*(WT(60)+WT(61)+WT(62)+WT(65)+WT(60)+T
C      1IRWT)/(WMAX/1000.))**.365*TK(67)
C      LANDING GEAR LESS CONTROLS
C      TG=0
C      DO 190 I=51,67
C      TG=TG+WT(I)
C      TG=TG+TIRWT
C

```

G1910
G1920
G1930
G1940
G1950
G1960
G1970
G1980
G1990
G2000
G2010
G2020
G2030
G2040
G2050
G2060
G2070
G2080-

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C      LANDING GEAR CONTROLS
C
C      WT(63)=.423*IG**.8**TK(68)
C
C      LANDING GEAR PLUS CONTROLS
C
C      WT(63)=0.
C      DO 200 I=51,68
C      INT=WT(I)+.5
C      WT(I)=INT
C      200 WT(63)=WT(69)+WT(I)
C
C      TOTAL LANDING GEAR GROUP
C
C      WT(63)=WT(63)+TIRWT+FIXED+TAIL3
C
C      RETURN
C      END

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WRITE (4,60) AR3
 WRITE (4,70) KE
 WRITE (4,300)
 WRITE (4,80) WT(51)
 WRITE (4,90) WT(52)
 WRITE (4,100) WT(53)
 WRITE (4,110) WT(54)
 WRITE (4,120) WT(55)
 WRITE (4,130) WT(56)
 WRITE (4,140) WT(57)
 WRITE (4,150) WT(58)
 WRITE (4,160) WT(59)
 WRITE (4,170) WT(60)
 WRITE (4,210) WT(61)
 WRITE (4,190) WT(62)
 WRITE (4,190) WT(63)
 WRITE (4,200) WT(64)
 WRITE (4,220) WT(65)
 WRITE (4,230) WT(66)
 WRITE (4,260) TIRWT
 WRITE (4,240) WT(67)
 WRITE (4,250) WT(68)
 WRITE (4,280) TAIL3
 WRITE (4,270) FIXFJ
 WRITE (4,290) WT(69)
 WRITE (4,320) IPWT(2)
 WRITE (4,330) WTF
 RETURN
 20 FORMAT (3X,12HLANDING GEAR,1X,6A10///
 30 FORMAT (1H1)
 40 FORMAT (3X,45HVS-LANDING CONF.POWER OFF STALL SPED KNOTS F15.2)
 50 FORMAT (3X,45HDESIGN LOAD /1000. F15.2)
 60 FORMAT (3X,45HDRAG BRACE FATIO F15.2)
 70 FORMAT (3X,45HKE-KINETIC ENERGY/1000 FT-LB F15.2)

C
 C
 C
 C

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80 FORMAT (9X,+5HMLG STRUC-SINGLE WHEEL-SINGLE WHEEL-VERT.COLUMN LAND BASEDF15.1) H 770
90 FORMAT (9X,+5HMLG STRUC-SINGLE WHEEL-SINGLE WHEEL-VERT.COLUMN CARR BASEDF15.1) H 780
100 FORMAT (9X,+5HMLG STRUC-MULTI WHEEL-VFRT.COLUMN LAND BASE F15.1) H 790
110 FORMAT (9X,+5HMLG STRUC-SINGLE WHEEL-TRIPOD TYPE LAND BASEDF15.1) H 800
120 FORMAT (9X,+5HMLG STRUC-SINGLE WHEEL-TRIPOD TYPE CARR BASEDF15.1) H 810
130 FORMAT (9X,+5HMLG STRUC-30MBERS AND FIGHTERS LAND BASEDF15.1) H 820
140 FORMAT (9X,+5HMLG STRUC-TRANSPORTS LAND BASEDF15.1) H 830
150 FORMAT (9X,+5HMLG STRUC-FIGHTER + ATTACK FUS TOW CARR BASEDF15.1) H 840
160 FORMAT (9X,+5HMLG STRUC-FIGHTER + ATTACK NOS TOW CARR BASEDF15.1) H 850
170 FORMAT (9X,+5HMLG ROLLING STOCK -WHEELS HIGH PRS LAND BASEDF15.1) H 860
180 FORMAT (9X,+5HMLG ROLLING STOCK -WHEELS CARR BASEDF15.1) H 870
190 FORMAT (9X,+5HMLG ROLLING STOCK -WHEELS F15.1) H 880
200 FORMAT (9X,+5HMLG ROLLING STOCK -WHEELS LOW PRS LAND BASEDF15.1) H 890
210 FORMAT (9X,+5HMLG ROLLING STOCK -WHEELS LOW PRS LAND BASEDF15.1) H 900
220 FORMAT (9X,+5HTIRES-TYPE III AND VII F15.1) H 910
230 FORMAT (9X,+5HTIRES-TYPE VIII F15.1) H 920
240 FORMAT (9X,+5HMLG ROLLING STOCK F15.1) H 930
250 FORMAT (9X,+5HMLG ROLLING GEAR CONTROLS F15.1) H 940
260 FORMAT (9X,+5HTIRE WT. INPUT F15.1) H 950
270 FORMAT (9X,+5HFIXED STRUCTURE F15.1) H 960
280 FORMAT (9X,+5HTAIL BUMPER WT. F15.1) H 970
290 FORMAT (//,3X,+4HTOTAL LANDING GEAR F17.1) H 980
300 FORMAT (//,9X,+5HWEIGHTS //) H 990
310 FORMAT (//,9X,+5HOUTPUT //) H1000
320 FORMAT (//,9X,+4HACTUAL WEIGHT F16.1 H1010
1) H1020
330 FORMAT (//,9X,+4HWEIGHT FACTOR F16.3 H1030
1) H1040
END H1050-

```


I	399
I	400
I	410
I	420
I	430
I	440
I	450
I	460
I	470
I	480
I	490
I	500
I	510
I	520
I	530
I	540
I	550
I	560
I	570
I	580
I	590
I	600
I	610
I	620
I	630
I	640
I	650
I	660
I	670
I	680
I	690
I	700
I	710
I	720
I	730
I	740
I	750
I	760

PYLONS

SINGLE ENGINE INSTALLATIONS

IF (COS(LESPYL/RAD)).NE.0.0) WT(31)=24.11*NPYL*(KFYL*ULF**WNC*LN*D4/
 110.0**6/COS(LESPYL/RAD))**C.952*SPYL**C.381

SIAMPSF ENGINE INSTALLATIONS

IF (COS(LESPYL/RAD).NE.0.0) WT(32)=340.25*NPYL*(KG*ULF**WNC*SPYL/10
 1.0**5/COS(LESPYL/RAD))**J.693

TUROPROP

COWLING

WT(83)=11.81*NN*(WNC*SN*RA/10.0**3)**0.593

MAIN LANDING GEAR DOORS

WT(84)=0.1611*V3*(SMD/2.0)**2.05

PISTON ENGINES

NACELLES WITH COWL FLAPS

WT(85)=35.97*NN*(WNC*SN*RA/10.0**3)**0.465

NACELLES WITH AIR PLUGS,BAFFLES,ETC.

WT(86)=45.63*NN*(WNC*SN*RA/10.0**3)**0.382

MAIN LANDING GEAR DOORS

WT(87)=0.1611*V3*(SMD/2.0)**2.05

TOTAL NACELLE GROUP WEIGHT

```

I 770
I 780
I 790
I 800
I 810
I 820
I 830
I 840
I 850-

```

```

C      TN=J.0
      DO 20 I=80,87
      WT(I)=WT(I)*TK(I)
      20 TN=TN+WT(I)
C
C      RETURN
      END

```



```

WRITE (4,140)
WRITE (4,113) TN
WRITE (4,160) IPWT(3)
WTF=IPWT(3)/TN
WRITE (4,150) WTF

C
C
C
C
      RETURN

20 FORMAT (9X,18H
30 FORMAT (9X,42H
40 FORMAT (9X,42H
50 FORMAT (9X,42H
60 FORMAT (9X,42H
70 FORMAT (9X,42H
80 FORMAT (9X,42H
90 FORMAT (9X,42H
100 FORMAT (9X,42H
110 FORMAT (9X,42H
120 FORMAT (1H1)
130 FORMAT (//)
140 FORMAT (//)
150 FORMAT (11X,40HWEIGHT FACTOR
160 FORMAT (11X,40HACTUAL WEIGHT
      END

7 8 9 IN COL 1

```

```

NACELLE WEIGHT ,BA10//)
JET ENGINE COWLING
JET ENGINE PYLONS SINGLE ENGINE
JET ENGINE PYLONS SIAMORE ENGINE
TURBOPROP COWLING
TURBOPROP MAIN LANDING GEAR DOOR
PISTON ENGINES NAC WITH COWL FLAPS
PISTON ENGINES NAC WITH AIR PLUGS
PISTON ENGINES MAIN LANDING GEAR DOORS
TOTAL NACELLE GROUP
F10.1//)
F10.1//)
F10.1//)
F10.1//)
F10.1//)
F10.1//)
F10.1//)
F10.1//)
F10.1//)
F10.1//)
F10.3)
F10.1//)

```

J 390
 J 400
 J 410
 J 420
 J 430
 J 440
 J 450
 J 460
 J 470
 J 480
 J 490
 J 500
 J 510
 J 520
 J 530
 J 540
 J 550
 J 560
 J 570
 J 580
 J 590
 J 600
 J 610
 J 620
 J 630
 J 640-

P5DATA

C

TITLE=6CH 880 TEST CASE

C

TK(1)=1.0	,DEF=55H	BASIC SHELL	,
TK(2)=1.0	,DEF=55H	COCKPIT PROVISIONS	,
TK(3)=1.0	,DEF=55H	WLG PROVISIONS	,
TK(4)=1.0	,DEF=55H	WLG CUTOUT / LOAD INTROD	,
TK(5)=1.0	,DEF=55H	WING REACTION (BODY TIE)	,
TK(6)=1.0	,DEF=55H	TAIL PROVISIONS	,
TK(7)=1.0	,DEF=55H	WINDSHIELD AND CANOPY	,
TK(8)=1.0	,DEF=55H	FWD VERTICAL INERTIA	,
TK(9)=1.0	,DEF=55H	AFT VERTICAL INERTIA	,
TK(10)=1.0	,DEF=55H	FWD SIDE BENDING	,
TK(11)=1.0	,DEF=55H	AFT SIDE BENDING	,
TK(12)=0.0	,DEF=55H	FWD FUEL INERTIA	,
TK(13)=0.0	,DEF=55H	AFT FUEL INERTIA	,
TK(14)=0.0	,DEF=55H	AFT ENGINE BENDING	,
TK(15)=1.0	,DEF=55H	AFT HORIZ. TAIL BENDING	,
TK(16)=0.0	,DEF=55H	FUEL PROVISIONS	,
TK(17)=0.0	,DEF=55H	APPROXIMATING GEAR PROVISIONS	,
TK(18)=0.0	,DEF=55H	CATAPULT/HOLDBACK FUS TOW	,
TK(19)=0.0	,DEF=55H	CATAPULT/HOLDBACK WLG TOW	,
TK(20)=0.0	,DEF=55H	ENGINE PROVISIONS	,
TK(21)=0.0	,DEF=55H	DUCT PROVISIONS	,
TK(22)=1.0	,DEF=55H	WLG DOORS	,
TK(23)=1.0	,DEF=55H	WLG CUTOUT/LOAD INTROD	,
TK(24)=0.0	,DEF=55H	EXTERNAL STORES PROV	,
TK(25)=0.0	,DEF=55H	SPEED BRAKES	,
TK(26)=0.0	,DEF=55H	30MM MISSILE BAY CUTOUT	,
TK(27)=0.0	,DEF=55H	B/M BAY DOORS+MECH CONVENT	,
TK(28)=0.0	,DEF=55H	B/M BAY DOORS+MECH ROTARY	,
TK(29)=1.0	,DEF=55H	CABIN FLOORING+SUPPORT TRN	,
TK(30)=1.0	,DEF=55H	CABIN WINDOWS TRANSPORTS	,
TK(31)=1.0	,DEF=55H	PRESSURE WE3+SEALANT TRN	,
TK(32)=0.0	,DEF=55H	AIR EXTRACTION PROV TRN	,
TK(33)=0.0	,DEF=55H	CARGO LOADING RAMP+ACC TRN	,
TK(34)=0.0	,DEF=55H	WLG EXTERNAL FAIRINGS	,

TK(35)=1.0	, DEF=55H	SIDE LOADING DOOR+MECH	,
TK(36)=0.0	, DEF=55H	CLAMHELL DOORS+MECH	,
TK(37)=0.0	, DEF=55H	FLAT CARGO CLEARANCE	,
TK(38)=0.0	, DEF=55H	FUEL TANK FLOORING	,
TK(39)=0.0	, DEF=55H	SWING TAIL/NOSE PROVISIONS	,
TK(40)=0.0	, DEF=55H	OVER WING FAIRING	,
TK(41)=0.0	, DEF=55H	WING SLOT SEAL	,
TK(42)=0.0	, DEF=55H	WING GLOVE	,
TK(43)=0.0	, DEF=55H	WINDSHIELD FAIRING AREA	,
TK(44)=1.0	, DEF=55H	BODY CONFIG. PENALTIES (MISC WT.)	,
TK(45)=1.0	, DEF=55H	FUSFLAGE MISC WEIGHT (STATISTICAL CORRECTION)	,
TK(51)=0.0	, DEF=55H	MLG STRUC-SINGLE WHEEL-VERT.COLUMN LAND BASED	,
TK(52)=0.0	, DEF=55H	MLG STRUC-SINGLE WHEEL-VERT.COLUMN CAR BASED	,
TK(53)=1.0	, DEF=55H	MLG STRUC-MULTIE WHEEL-VERT.COLUMN LAND BASED	,
TK(54)=0.0	, DEF=55H	MLG STRUC-SINGLE WHEEL-TRIPOD TYPE LAND BASED	,
TK(55)=0.0	, DEF=55H	MLG STRUC-SINGLE WHEEL-TRIPOD TYPE CAR BASED	,
TK(56)=0.0	, DEF=55H	MLG STRUC-BOMBERS AND FIGHTERS LAND BASED	,
TK(57)=1.0	, DEF=55H	MLG STRUC-TRANSPORTS LAND BASED	,
TK(58)=0.0	, DEF=55H	MLG STRUC-FIGHTER + ATTACK FUS TOW CAR BASED	,
TK(59)=0.0	, DEF=55H	MLG STRUC-FIGHTER + ATTACK NOS TOW CAR BASED	,
TK(60)=1.0	, DEF=55H	MLG ROLLING STOCK -WHEELS HIGH PRS LAND BASED	,
TK(61)=0.0	, DEF=55H	MLG ROLLING STOCK -WHEELS LOW PRS LAND BASED	,
TK(62)=0.0	, DEF=55H	MLG ROLLING STOCK -WHEELS HIGH PRS CAR BASED	,
TK(63)=1.0	, DEF=55H	BRKFS -NO DRAG CHUTE	,
TK(64)=0.0	, DEF=55H	BRKFS - DRAG CHUTE	,
TK(65)=1.0	, DEF=55H	TIRES-TYPE III AND VII	,
TK(66)=0.0	, DEF=55H	TIRES-TYPE VIII	,
TK(67)=1.0	, DEF=55H	MLG ROLLING STOCK	,
TK(68)=1.0	, DEF=55H	LANDING GEAR CONTROLS	,
TK(80)=2.0	, DEF=55H	EXT MOUNT JET ENGINE COWLING	,
TK(81)=2.0	, DEF=55H	EXT MOUNT JET ENGINE PYLON SINGLE ENGINE INSTALLATION,	,
TK(82)=0.0	, DEF=55H	EXT MOUNT JET ENGINE PYLON SIAMESEENGINE INSTALLATION,	,
TK(83)=0.0	, DEF=55H	EXT MOUNT TURBOPROP COWLING	,
TK(84)=0.0	, DEF=55H	MAIN LANDING GEAR DOORS (JET-TURBOPROP)	,
TK(85)=0.0	, DEF=55H	NACELLEFS WITH COWL FLAPS (PISTON ENGINE)	,
TK(86)=0.0	, DEF=55H	NACELLEFS WITH AIR RAFFLES (PISTON ENGINE)	,
TK(87)=0.0	, DEF=55H	MAIN LANDING GEAR DOORS (PISTON ENGINE)	,
AF =785.0	, DEF=55H	CABIN FLOOR AREA -SQ FT	,

AGL	= 88.0	WINDOW AREA, CABIN, TRANSPORTS -SQ FT	,
AN	= 3.80	MAXIMUM NACELLE BREAOTH-FT	,
BOBY	= 500.0	FIXED BODY WEIGHT-LBS	,
BP	= 142.0	WING SPAN ALONG 50 PC CHORD-FT	,
CD	= 0.0	SPEED BRAKE DRAG COEFFICIENT	,
CE	= 0.0	INLET DUCT CIRCUMFERENCE AT ENGINE-FT/DUCT	,
CF	= 0.0	FUS CIRCUMFERENCE-FT	,
CI	= 0.0	INLET DUCT CIRCUMFERENCE AT INLET-FT/DUCT	,
CL	= 1.65	LIFT COEFFICIENT LANDING CONFIGURATION	,
CSDA	= 0.0	CLAMSHELL CR AND MECH AREA-SQ FT/AP	,
DAF	= 9.37	AFT FUS AVG VERTICAL BENDING DEPTH-FT	,
DC	= 0.0	ULTIMATE ARRESTING HOOK DRAG COMPONENT-LF	,
DCK	= 0.0	0 SUB-C CONSTANT (MULTIPLYING CONSTANT FOR DC)	,
DE	= 0.0	ENGINE COMPARTMENT DIAMETER-FT	,
DEF	= 9.37	FWD FUS AVG VERTICAL BENDING DEPTH-FT	,
DMB	= 0.0	30MB OR MISSILE BAY WIDTH-FT	,
DN	= 4.40	MAXIMUM NACELLE DEPTH-FT	,
DT	= 0.0	MAXIMUM OUTSIDE DIAMETER OF 4LG TIRES-INS	,
DWA	= 9.25	AFT FUS AVG SIDE BENDING WIDTH-FT	,
DWF	= 9.25	FWD FUS AVG SIDE BENDING WIDTH-FT	,
DWH	= 16.0	BEAD LEDGE DIAMETER-INS	,
ECODA	= 0.0	FLAT CGO CLEARANCE DR, AREA-SQ FT	,
FH	= 0.0	HORIZONTAL TAIL LOAD-LBS	,
FIXED	= 191.0	FIXED STRUCTURE (LANDING GEAR)-LBS	,
FLAG	= 0.0	1 BODY, NAC, LG-1 BODY-2 LG-3 NAC	,
FTFA	= 0.0	FUEL TANK FLOORING AREA-SQ FT	,
FV	= 0.0	VERTICAL TAIL LOAD-LBS	,
FVM	= 0.0	MAIN GEAR VERTICAL LOAD-LBS/SIDE	,
FVN	= 0.0	NOSE VERTICAL LOAD-LBS	,
GF	= 0.0	FUSELAGE FUEL CAPACITY (GALLONS)	,
HTVC	= 0.6733	HORIZONTAL TAIL VOLUME COEFFICIENT	,
IPWT (1)	= 13699.0	ACTUAL WEIGHT OF GROUP BODY-LBS	,
IPWT (2)	= 6333.00	ACTUAL WEIGHT OF GROUP LANDING GEAR-LBS	,
IPWT (3)	= 3685.00	ACTUAL WEIGHT OF GROUP NAC-LBS	,
K	= 24.0	WINDSHIELD AND CANOPY CONSTANT	,
K3	= 0.0	30MB BAY TYPE FACTOR	,
KF	= 0.0	FUS FUEL TANK CONSTANT	,
KS	= 0.0	FACTOR=1.0 NO GEAR IN NAC =1.265 GEAR IN NACELLE	,

KMA	=1.0	MLG STRUCTURE TYPE FACTOR-1 TRAN-0.733 BOMBERS
KMLD	=3.223	MLG DOORS TYPE CONSTANT
KY	=1.0	NACELLE TYPE CONSTANT (SEE USERS GUIDE)
KND	=1.0	NOSE GEAR DESIGN CRITERIA-SEE MANUAL
KPYL	=1.46	FACTOR=1 FOR MIL TRAN AND BOMB =2 COMMERCIAL
KS	=0.0	EXTERNAL STORES CONSTANT
LAF	=0.0	LENGTH C/L WING BOX/ CG AFT FUEL)-FT
LAL	=66.0	AFT LONGERON LENGTH C/L WING AFT-FT
LR	=40.0	BRACE LENGTH- C/L TRUNNION TO GRAB BRACE FTG-INS
LD	=0.0	INLET DUCT LENGTH (C/L DUCT)-FT/DUCT
LE	=0.0	ENGINE COMPARTMENT LENGTH-FT
LESPLY	=73.0	PYLON LEADING EDGE SWEEP ANGLE - DEGREES
LEX	=83.0	MLG EXTENDED LENGTH C/L (TRUN/AXLE)-INS
LEXN	=63.3	MLG EXTENDED LENGTH C/L (TRUN/AXLE)-INS
LEF	=0.0	LENGTH C/L WING BOX/ CG FWD FUEL)-FT
LFL	=48.5	FWD LONGERON LENGTH C/L WING/ R BHC-FT
LFLR	=0.0	CARGO FLOOR LENGTH-FT
LGF	=0.0	LANDING GEAR FAIRING LENGTH-FT
LHT	=57.75	LENGTH C/L WING BOX/ C/L HT BOX)-FT
LMR	=0.0	TOTAL BOMB OR MISSILE BAY LENGTH-FT
LN	=16.5	NACELLE COWL LENGTH- FT
LNXY	=0.0	NOT USED
LPO	=0.0	LENGTH C/L WING BOX/ CG ENG INSTL)-FT
LRA	=0.0	CGO RAMP LENGTH -FT.
LTR	=0.0	STRUT LENGTH ABOVE TRUNNION-INS
LVT	=56.4	LENGTH C/L WING BOX/ C/L FIN BOX)-FT
LWS	=0.0	LENGTH OF WING SLOT-FT
ND	=0.0	NUMBER OF INLET DUCTS
NE	=0.0	NUMBER OF ENGINES PER AIRPLANE
NE	=0.0	NUMBER OF FUSELAGE FUEL TANKS
NE	=0.0	NUMBER OF MLG INSTALLATIONS PER A/P
NL	=2.5	DESIGN LANDING ULTIMATE LOAD FACTOR
NN	=2.0	NUMBER OF LIKE NACELLES PER AIRPLANE
NPYL	=2.0	NUMBER OF LIKE PYLONS PER AIRPLANE
NS	=0.0	NUMBER OF STORE STATIONS
NS1	=0.0	NUMBER OF STORE STATIONS 1
NS2	=0.0	NUMBER OF STORE STATIONS 2
NSR	=0.0	NUMBER OF SPEED BRAKES

NST	=2.0	,DEF=55H	NUMBER OF MLG STRUTS PER AF	,
NT	=3.0	,DEF=55H	TAXI LOAN FACTOR-ULTIMATE	,
NTI	=8.0	,DEF=55H	NUMBER MAIN LANDING TIRES PER AIRPLANE	,
NWH	=8.0	,DEF=55H	NUMBER MAIN LANDING GEAR WHEELS	,
NX	=0.0	,DEF=55H	CATAPULT LOAD FACTOR (ULTIMATE)	,
PC	=17.2	,DEF=55H	ULTIMATE CABIN PRESSURE	,
PCW	=0.0	,DEF=55H	SFF MANUAL	,
PD	=0.0	,DEF=55H	DUCT PRESSURE-PSI (COMPUTED IF BLANK)	,
C	=475.0	,DEF=55H	MAX OPERATING DYNAMIC PRESSURE-PSF	,
SC	=42.0	,DEF=55H	WINDSHIELD AND CANOPY AREA-SQ FT	,
S2A	=107.6	,DEF=55H	SIDE LOADING DOOR AND MECH-SQ FT	,
SFF	=3513.0	,DEF=55H	FUSPLAGE WETTED AREA MINUS CUTOUTS-SQ FT	,
SCW	=0.0	,DEF=55H	WINDSHIELD FAIRING AREA-SQ FT	,
SGF	=0.0	,DEF=55H	LANDING GEAR FAIRING AREA-SQ FT	,
SGL	=0.0	,DEF=55H	GLOVE SURFACE AREA-SQ FT	,
SW	=20.0	,DEF=55H	MLG STROKE (INCHES)	,
SWB	=0.0	,DEF=55H	MISSILE OR BOMB BAY DR., FT SQ	,
SYD	=66.92	,DEF=55H	MLG COOR AREA-SQ FT	,
SN	=200.0	,DEF=55H	NACELLE COWL SURFACE AREA-FT SQ/ NAC	,
SVD	=10.8	,DEF=55H	MLG DOOR AREA-SQ FT	,
SPVL	=46.5	,DEF=55H	PYLON PLANFORM AREA - FT SQ/ NACELLE	,
S2A	=0.0	,DEF=55H	CARGO RAMP AREA-SQ FT	,
SSB	=0.0	,DEF=55H	SPEED BRAKE AREA EACH-SQ FT	,
SW	=2000.0	,DEF=55H	WING AREA-THEO SQ FT	,
SWF	=0.0	,DEF=55H	OVER WING FAIRING AREA-SQ FT	,
SWP	=2833.0	,DEF=55H	CARGO AND PASS COMPARTMENT WETTED AREA-SQ FT	,
TAILB	=6.0	,DEF=55H	TAIL BUMPER WEIGHT-LBS	,
TIPWT	=703.0	,DEF=55H	TIRE WEIGHT IF INPUT-LBS	,
TPF	=0.0	,DEF=55H	THROUST PFR ENGINE-LBS	,
TYPE	=3.0	,DEF=55H	FLAG (C USAF, 1USN, 2 BOMBER, 3 TRANSPORT)	,
ULF	=3.75	,DEF=55H	FLIGHT DESIGN ULTIMATE LOAD FACTOR	,
VC	=395.0	,DEF=55H	COCKPIT VOLUME-CU FT	,
VS	=0.0	,DEF=55H	STALL SPEED (COMPUTED IF BLANK)-FT/SFC	,
WAI	=46524.0	,DEF=55H	WT AFTBODY EXCLUD.FUEL AFT C/L WING-LBS	,
WC	=0.0	,DEF=55H	CATAPULT DESIGN GROSS WEIGHT-LBS	,
WJES	=185000.0	,DEF=55H	DESIGN GROSS WEIGHT-LBS	,
WF	=75.0	,DEF=55H	1 G DESIGN FLOOR LOADING-LBS	,
WEA	=0.0	,DEF=55H	WT AFTBODY FUEL AT DESIGN CONDITION-LBS	,

WFF	=0.0	,DEF=55H	WT FWD BODY FUEL AT DESIGN CONDITION-LBS	,
WFL	=10.0	,DEF=55H	WHEEL WIDTH BETWEEN FLANGES-INS	,
WFI	=24678.0	,DEF=55H	WT FWD BODY EXCLUD.FUEL FWD C/L WING-LBS	,
WLAND	=185000.0	,DEF=55H	DESIGN LANDING WEIGHT-LBS	,
WMAX	=185000.0	,DEF=55H	MAXIMUM GROSS WEIGHT-LBS	,
WNC	=3340.0	,DEF=55H	WEIGHT OF MACELLE CONTENTS-LBS	,
WPP	=0.0	,DEF=55H	WT OF ENGINE INSTALLATION-LBS	,
WS	=0.0	,DEF=55H	DESIGN STORE WEIGHT PER STA-LBS	,
WS1	=0.0	,DEF=55H	WT AT STORE STATION 1-LRS	,
WS2	=0.0	,DEF=55H	WT AT STORE STATION 2-LRS	,
WTI	=0.0	,DEF=55H	TIRE MAXIMUM SECTION WIDTH-INS	,
WTP(1,1)	=9009.0	,DEF=55H	INPUT FROM APASS PANELS-LBS	,
WTP(2,1)	=0.0	,DEF=55H	INPUT FROM APASS LONGERON-LBS	,
WTP(3,1)	=1270.5	,DEF=55H	INPUT FROM APASS FRAMES-LBS	,
WTP(4,1)	=655.05	,DEF=55H	INPUT FROM APASS WEBS-LBS	,
WTP(5,1)	=0.0	,DEF=55H	INPUT FROM APASS NON-STRUCTURAL-LBS	,
WWE	=0.0	,DEF=55H	MAX WEAPON WT-LBS	,

C \$ END

P3DATA

C

TITLE=60H B-53A TEST CASE

C

TK(1)=1.0	,DEF=55H	BASIC SHELL	,
TK(2)=1.0	,DEF=55H	COCKPIT PROVISIONS	,
TK(3)=1.0	,DEF=55H	NLG PROVISIONS	,
TK(4)=1.0	,DEF=55H	NLG CUTOFF / LOAD INTROD	,
TK(5)=1.0	,DEF=55H	WING REACTION (90DY TIE)	,
TK(6)=1.0	,DEF=55H	TAIL PROVISIONS	,
TK(7)=1.0	,DEF=55H	WINDSHIELD AND CANOPY	,
TK(8)=1.0	,DEF=55H	FWD VERTICAL INERTIA	,
TK(9)=1.0	,DEF=55H	AFT VERTICAL INERTIA	,
TK(10)=1.0	,DEF=55H	FWD SIDE BENDING	,
TK(11)=1.0	,DEF=55H	AFT SIDE BENDING	,
TK(12)=1.0	,DEF=55H	FWD FUEL INERTIA	,
TK(13)=1.0	,DEF=55H	AFT FUEL INERTIA	,
TK(14)=0.0	,DEF=55H	AFT ENGINE BENDING	,
TK(15)=0.0	,DEF=55H	AFT HORI7. TAIL BENDING	,
TK(16)=1.0	,DEF=55H	FUEL PROVISIONS	,
TK(17)=0.0	,DEF=55H	ARRESTING GEAR PROVISIONS	,
TK(18)=0.0	,DEF=55H	CATAPULT/HOLOBACK FUS TOW	,
TK(19)=0.0	,DEF=55H	CATAPULT/HOLOBACK NLG TOW	,
TK(20)=0.0	,DEF=55H	ENGINE PROVISIONS	,
TK(21)=0.0	,DEF=55H	DUCT PROVISIONS	,
TK(22)=0.0	,DEF=55H	NLG DOORS	,
TK(23)=0.0	,DEF=55H	NLG CUTOFF/LOAD INTROD	,
TK(24)=1.0	,DEF=55H	EXTERNAL STORES PROCV	,
TK(25)=0.0	,DEF=55H	SPEED BRAKES	,
TK(26)=0.0	,DEF=55H	BOMB/MISSLE 3AY CUTOFF	,
TK(27)=0.0	,DEF=55H	3/M 3AY DOORS+MECH CONVENT	,
TK(28)=0.0	,DEF=55H	3/M 3AY DOORS+MECH ROTARY	,
TK(29)=0.0	,DEF=55H	CABIN FLOORING+SUPPORT TRN	,
TK(30)=0.0	,DEF=55H	CABIN WINDOWS TRANSPORTS	,
TK(31)=0.0	,DEF=55H	PRESSURE WEB+SEALANT TRN	,
TK(32)=0.0	,DEF=55H	AIR EXTRACTION PROV TRN	,
TK(33)=0.0	,DEF=55H	CARGO LOADING RAMP+ACC TRN	,
TK(34)=0.0	,DEF=55H	NLG EXTERNAL FAIRINGS	,

TK(35)=0.0	DEF=55H	SIDE LOADING DOOR+MECH	,
TK(36)=0.0	DEF=55H	CLAMSHLL COORS+MECH	,
TK(37)=0.0	DEF=55H	FLAT CARGO CLEARANCE	,
TK(38)=0.0	DEF=55H	FUFL TANK FLOORING	,
TK(39)=0.0	DEF=55H	SWING TAIL/NOSE PROVISIONS	,
TK(40)=0.0	DEF=55H	OVER WING FAIRING	,
TK(41)=0.0	DEF=55H	WING SLOT SEAL	,
TK(42)=0.0	DEF=55H	WING GLOVE	,
TK(43)=0.0	DEF=55H	WINDSHIELD FAIRING AREA	,
TK(44)=0.0	DEF=55H	BODY CNFIG. PENALTIES	,
TK(45)=1.0	DEF=55H	FUSELAGE MISC WFLIGHT (STATISTICAL CORRECTION)	,
TK(51)=0.0	DEF=55H	MLG STRUC-SINGLE WHEEL-VERT.COLUMN LAND BASED	,
TK(52)=0.0	DEF=55H	MLG STRUC-SINGLE WHEEL-VERT.COLUMN CAR- BASED	,
TK(53)=1.0	DEF=55H	MLG STRUC-MULTIF WHEEL-VERT.COLUMN LAND BASED	,
TK(54)=0.0	DEF=55H	MLG STRUC-SINGLE WHEEL-TRIFOD TYPE LAND BASED	,
TK(55)=0.0	DEF=55H	MLG STRUC-SINGLE WHEEL-TRIFOD TYPE CAR BASED	,
TK(56)=1.0	DEF=55H	MLG STRUC-BOMBERS AND FIGHTERS	,
TK(57)=0.0	DEF=55H	MLG STRUC-TRANSPORTS	,
TK(58)=0.0	DEF=55H	MLG STRUC-FIGHTER + ATTACK FUS TOW CAR BASED	,
TK(59)=0.0	DEF=55H	MLG STRUC-FIGHTER + ATTACK NOS TOW CAR BASED	,
TK(60)=1.0	DEF=55H	MLG ROLLING STOCK -WHEELS HIGH PRS LAND BASED	,
TK(61)=0.0	DEF=55H	MLG ROLLING STOCK -WHEELS LOW PRS LAND BASED	,
TK(62)=0.0	DEF=55H	MLG ROLLING STOCK -WHEELS HIGH PRS CAR BASED	,
TK(63)=0.0	DEF=55H	BRAKES -NO DRAG CHUTE	,
TK(64)=1.0	DEF=55H	BRAKES - DRAG CHUTE	,
TK(65)=0.0	DEF=55H	TIRES-TYPE III AND VII	,
TK(66)=0.0	DEF=55H	TIRES-TYPE VIII	,
TK(67)=1.0	DEF=55H	MLG ROLLING STOCK	,
TK(68)=1.0	DEF=55H	LANDING GEAR CONTROLS	,
TK(80)=1.0	DEF=55H	EXT MOUNT JET ENGINE COWLING	,
TK(81)=1.0	DEF=55H	FXT MOUNT JET ENGINE PYLON SINGLE ENGINE INSTALLATION,	,
TK(82)=0.0	DEF=55H	EXT MOUNT JET ENGINE PYLON SIAMESEENGINE INSTALLATION,	,
TK(83)=0.0	DEF=55H	EXT MOUNT TURBOPROP COWLING	,
TK(84)=0.0	DEF=55H	MAIN LANDING GEAR DOORS(JET-TURBOPROP)	,
TK(85)=0.0	DEF=55H	NACELLES WITH COWL FLAPS (PISTON ENGINE)	,
TK(86)=0.0	DEF=55H	NACELLES WITH AIR RAFFLES(PISTON ENGINE)	,
TK(87)=0.0	DEF=55H	MAIN LANDING GEAR DOORS (PISTON ENGINE)	,
AF =0.0	DEF=55H	CABIN FLOOR AREA -SQ FT	,

AGL	= 0.0	WINDOW AREA, CABIN, TRANSPORTS -SQ FT
BN	= 4.01	MAXIMUM NACELLE REFADTH-FT
BODY	= 0.0	FIXED BODY WEIGHT-LBS
BP	= 72.	WING SPAN ALONG 50 PC CHORD-FT
CD	= 0.0	SPEED BRAKE DRAG COEFFICIENT
CE	= 0.0	INLET DUCT CIRCUMFERENCE AT ENGINE-FT/DUCT
CF	= 0.0	FUS CIRCUMFERENCE-FT
CI	= 0.0	INLET DUCT CIRCUMFERENCE AT INLET-FT/DUCT
CL	= 1.6	LIFT COEFFICIENT LANDING CONFIGURATION
CSDA	= 0.0	CLAMSHELL DR AND WFOH AREA-SQ FT/AP
DAF	= 4.17	AFT FUS AVG VERTICAL BENDING DEPTH-FT
DC	= 0.0	ULTIMATE ARRESTING HOOK DRAG COMPONENT-LF
DCK	= 0.0	D SUR-C CONSTANT (MULTIPLYING CONSTANT FOR DC)
DE	= 0.0	ENGINE COMPARTMENT DIAMETER-FT
DEF	= 4.33	FWD FUS AVG VERTICAL BENDING DEPTH-FT
DHR	= 0.0	30M9 OF MISSILE BAY WIDTH-FT
DN	= 4.5	MAXIMUM NACELLE DEPTH-FT
DT	= 0.0	MAXIMUM OUTSIDE DIAMETER OF WLG TIRES-INS
DWA	= 2.75	AFT FUS AVG SIDE BENDING WIDTH-FT
DWF	= 3.31	FWD FUS AVG SIDE BENDING WIDTH-FT
DWH	= 12.	BEAD LEDGE DIAMETER-INS
ECODA	= 0.0	FLAT CGO CLEARANCE DR, AREA-SQ FT
EH	= 0.0	HORIZONTAL TAIL LOAD-LBS
FIXED	= 0.0	FIXED STRUCTURE (LANDING GEAR)-LBS
FLAG	= 0.0	J BODY, NAC, LG-1 BODY-2 LG-3 NAC
FTFA	= 0.0	FUEL TANK FLOORING AREA-SQ FT
FV	= 0.0	VERTICAL TAIL LOAD-LBS
FVM	= 0.0	MAIN GEAR VERTICAL LOAD-LBS/SIDE
FVN	= 0.0	NOSE VERTICAL LOAD-LBS
GF	= 3778.	FUSELAGE FUEL CAPACITY (GALLONS)
HTVC	= .0714	HORIZONTAL TAIL VOLUME COEFFICIENT
IPWT(1)	= 5174.	ACTUAL WEIGHT OF BODY GROUP-LB
IPWT(2)	= 3412.	ACTUAL WEIGHT LANDING GEAR GROUP-LB
IPWT(3)	= 4675.	ACTUAL WEIGHT NACELLE GROUP-LB
K	= 19.9	WINDSHIELD AND CANOPY CONSTANT
KR	= 0.0	30M9 RAY TYPE FACTOR
KF	= .75	FUS FUEL TANK CONSTANT
KS	= 0.0	FACTOR=1.0 NO GEAR IN NAC =1.265 GEAR IN NACELLE

KYA	= .476	MLG STRUCTURE TYPE FACTOR-1 TRAN-0.733 BOMBERS	,
KMLD	= 0.0	MLG DOORS TYPE CONSTANT	,
KN	= 2.15	NACELLE TYPE CONSTANT (SEE USERS GUIDE)	,
KNO	= .47	NOSE GEAR DESIGN CRITERIA-SEE MANUAL	,
KPYL	= 1.0	FACTOR=1 FOR MIL TRAN AND BOMB =2 COMMERCIAL	,
KS	= .067	EXTERNAL STORES CONSTANT	,
LAF	= 14.83	LENGTH(C/L WING BOX/ CG AFT FUEL)-FT	,
LAL	= 30.17	AFT LONGERON LENGTH C/L WING AFT-FT	,
L3	= 04.5	BRACE LENGTH- C/L TRUNNION TO DRAG BRACE FT3-INS	,
LD	= 0.0	INLET DUCT LENGTH (C/L DUCT)-FT/DUCT	,
LE	= 0.0	ENGINE COMPARTMENT LENGTH-FT	,
LESPYL	= 77.	PYLON LEADING EDGE SWEEP ANGLE - DEGREES	,
LEX	= 123.3	MLG EXTENDED LENGTH C/L (TRUN/AXLE)-INS	,
LFXN	= 108.9	NLG EXTENDED LENGTH C/L (TRUN/AXLE)-INS	,
LFF	= 8.75	LENGTH(C/L WING BOX/ CG FWD FUEL)-FT	,
LFL	= 41.25	FWD LONGERON LENGTH C/L WING/ R BHD-FT	,
LFLR	= 0.0	CARGO FLOOR LENGTH-FT	,
LGF	= 0.0	LANDING GEAR FAIRING LENGTH-FT	,
LHT	= 0.0	LENGTH(C/L WING BOX/ C/L HT BOX)-FT	,
LHR	= 0.0	TOTAL BOMB OR MISSILE RAY LENGTH-FT	,
LY	= 22.28	NACELLE COWL LENGTH- FT	,
LNX	= 0.0	NOT USED	,
LPP	= 0.0	LENGTH(C/L WING BOX/ CG ENG INSTL)-FT	,
LRA	= 0.0	CGO KAMP LENGTH -FT.	,
LTP	= 0.0	STRUT LENGTH ABOVE TRUNNION-INS	,
LVT	= 27.25	LENGTH (C/L WING BOX/ C/L FIN BOX)-FT	,
LWS	= 0.0	LENGTH OF WING SLOT-FT	,
ND	= 0.0	NUMBER OF INLET DUCTS	,
NE	= 0.0	NUMBER OF ENGINES PER AIRPLANE	,
NF	= 3.0	NUMBER OF FUSELAGE FUEL TANKS	,
NG	= 0.0	NUMBER OF MLG INSTALLATIONS PER A/P	,
NL	= 3.5	DESIGN LANDING ULTIMATE LOAD FACTOR	,
NN	= 4.0	NUMBER OF LIKE NACELLES PER AIRPLANE	,
NPYL	= 2.0	NUMBER OF LIKE PYLONS PER AIRPLANE	,
NS	= 0.0	NUMBER OF STORE STATIONS	,
NS1	= 1.0	NUMBER OF STORE STATIONS 1	,
NS2	= 0.0	NUMBER OF STORE STATIONS 2	,
NSB	= 0.0	NUMBER OF SPEED BRAKES	,

NST	= 2.0	NUMBER OF MLG STRUTS PER AP	,
NT	= 3.0	TAXI LOAD FACTOR-ULTIMATE	,
NTI	= 0.0	NUMBER MAIN LANDING TIRES PER AIRPLANE	,
NMH	= 16.	NUMBER MAIN LANDING GEAR WHEELS	,
NX	= 0.0	CATAULT LOAD FACTOR (ULTIMATE)	,
PC	= 14.9	ULTIMATE CABIN PRESSURE	,
PCW	= 0.0	SEE MANUAL	,
PJ	= 0.0	DUCT PRESSURE-PSI (COMPUTED IF BLANK)	,
G	= 1336.	MAX OPERATING DYNAMIC PRESSURE-PSF	,
SC	= 153.	WINDSHIELD AND CANOPY AREA-SQ FT	,
STA	= 0.0	SIDE LOADING DOOR AND MECH-SQ FT	,
SFF	= 1220.	FUSELAGE WETTED AREA MINUS CUTOOTS-SQ FT	,
SEW	= 0.0	WINDSHIELD FAIRING AREA-SQ FT	,
S3F	= 0.0	LANDING GEAR FAIRING AREA-SQ FT	,
SGL	= 0.0	GLOVE SURFACE AREA-SQ FT	,
SM	= 15.	MLG STROKE (INCHES)	,
SM3	= 0.0	MISSILE OR BOMB BAY DR., FT SQ	,
SYD	= 0.0	MLG WGOR AREA-SQ FT	,
SN	= 258.	NACELLE COWL SURFACE AREA-FT SQ/ NAC	,
SND	= 27.4	MLG DOOR AREA-SQ FT	,
SPYL	= 56.	PYLON PLANFORM AREA - FT SQ/ NACELLE	,
SPA	= 0.0	CARGO RAMP AREA-SQ FT	,
SSR	= 0.0	SPEED BRAKE AREA EACH-SQ FT	,
SW	= 1542.5	WING AREA-THEO SQ FT	,
SWF	= 0.0	OVER WING FAIRING AREA-SQ FT	,
SWP	= 0.0	CARGO AND PASS COMPARTMENT WETTED AREA-SQ FT	,
TAILB	= 0.0	TAIL BUMPER WEIGHT-LBS	,
TIRWT	= 444.	TIRE WEIGHT IF INPUT-LBS	,
TPE	= 0.0	THRUST PER ENGINE-LBS	,
TYPE	= 2.0	FLAG (C USAF, 1USN, 2 BOMBER, 3 TRANSPORT)	,
ULF	= 3.0	FLIGHT DESIGN ULTIMATE LOAD FACTOR	,
VC	= 163.	COCKPIT VOLUME-CU FT	,
VS	= 0.0	STALL SPEED (COMPUTED IF BLANK)-FT/SEC	,
WAI	= 5872.	WT AFTBODY EXCLUD.FUEL AFT C/L WING-LBS	,
WC	= 0.0	CATAULT DESIGN GROSS WEIGHT-LBS	,
WJES	= 163000.	DESIGN GROSS WEIGHT-LBS	,
WE	= 0.0	1 G DESIGN FLOOR LOADING-LBS	,
WEA	= 13576.	WT AFTBODY FUEL AT DESIGN CONDITION-LBS	,

WFF	=5878.	,DEF=55H	WT FWD BODY FUEL AT DESIGN CONDITION-LBS	,
WFL	=6.0	,DEF=55H	WHEEL WIDTH BETWEEN FLANGES-INS	,
WFI	=8135.	,DEF=55H	WT FWD BODY EXCLUD. FUEL FWD C/L WING-LBS	,
WLAND	=95000.	,DEF=55H	DESIGN LANDING WEIGHT-LBS	,
WMAX	=163000.	,DEF=55H	MAXIMUM GROSS WEIGHT-LBS	,
WNC	=3750.	,DEF=55H	WEIGHT OF NACELLE CONTENTS-LBS	,
WPD	=0.0	,DEF=55H	WT OF ENGINE INSTALLATION-LBS	,
WS	=0.0	,DEF=55H	DESIGN STORE WEIGHT PER STA-LBS	,
WS1	=36470.	,DEF=55H	WT AT STORE STATION 1-LBS	,
WS2	=0.0	,DEF=55H	WT AT STORE STATION 2-LBS	,
WTI	=0.0	,DEF=55H	TYPE MAXIMUM SECTION WIDTH-INS	,
WTP(1,1)	=2877.	,DEF=55H	INPUT FROM APAS - PANELS-LB	,
WTP(2,1)	=178.	,DEF=55H	INPUT FROM APAS - LONGERONS-LB	,
WTP(3,1)	=537.	,DEF=55H	INPUT FROM APAS - FRAMES-LB	,
WTP(4,1)	=488.	,DEF=55H	INPUT FROM APAS - WEBS-LB	,
WTP(5,1)	=0.0	,DEF=55H	INPUT FROM APAS - NON-STRUCTURAL-LB	,
WWF	=0.0	,DEF=55H	MAX WEAPON WT-LBS	,
3END				

P3DATA

C

TITLE=6CH AX TEST CASE

C

TK(1)=1.0	,DEF=55H	BASIC SHELL
TK(2)=1.0	,DEF=55H	COCKPIT PROVISIONS
TK(3)=1.0	,DEF=55H	NLG PROVISIONS
TK(4)=1.0	,DEF=55H	NLG CUTOFF / LOAD INTROD
TK(5)=1.0	,DEF=55H	WING REACTION (BODY TIE)
TK(6)=1.0	,DEF=55H	TAIL PROVISIONS
TK(7)=1.0	,DEF=55H	WINDSHIELD AND CANOPY
TK(8)=1.0	,DEF=55H	FWD VERTICAL INERTIA
TK(9)=1.0	,DEF=55H	AFT VERTICAL INERTIA
TK(10)=1.0	,DEF=55H	FWD SIDE BENDING
TK(11)=1.0	,DEF=55H	AFT SIDE BENDING
TK(12)=0.0	,DEF=55H	FWD FUEL INERTIA
TK(13)=0.0	,DEF=55H	AFT FUEL INERTIA
TK(14)=1.0	,DEF=55H	AFT ENGINE BENDING
TK(15)=1.0	,DEF=55H	AFT HORIZ. TAIL BENDING
TK(16)=0.0	,DEF=55H	FUEL PROVISIONS
TK(17)=0.0	,DEF=55H	ARRESTING GEAR PROVISIONS
TK(18)=0.0	,DEF=55H	CATAPULT/HOLDBACK FUS TOW
TK(19)=0.0	,DEF=55H	CATAPULT/HOLDBACK NLG TOW
TK(20)=1.0	,DEF=55H	ENGINE PROVISIONS
TK(21)=0.0	,DEF=55H	DUCT PROVISIONS
TK(22)=1.0	,DEF=55H	NLG DOORS
TK(23)=1.0	,DEF=55H	NLG CUTOFF/LOAD INTROD
TK(24)=1.0	,DEF=55H	EXTERNAL STORES PROV
TK(25)=1.0	,DEF=55H	SPEED BRAKES
TK(26)=1.0	,DEF=55H	30MM/MISSILE BAY CUTOFF
TK(27)=0.0	,DEF=55H	3/M BAY DOORS+MECH CONVENT
TK(28)=0.0	,DEF=55H	3/M BAY DOORS+MECH ROTARY
TK(29)=0.0	,DEF=55H	CABIN FLOORING+SUPPORT TRN
TK(30)=0.0	,DEF=55H	CABIN WINDOWS TRANSPORTS
TK(31)=0.0	,DEF=55H	PRESSURE WEB+SEALANT TRN
TK(32)=0.0	,DEF=55H	AIR EXTRACTION PROV TRN
TK(33)=0.0	,DEF=55H	CARGO LOADING RAMP+ACC TRN
TK(34)=0.0	,DEF=55H	NLG EXTERNAL FAIRINGS

TK(35)=0.0	, DEF=55H	SIDE LOADING DOOR+MECH	,
TK(36)=0.0	, DEF=55H	CLAMSHLL DOORS+MECH	,
TK(37)=0.0	, DEF=55H	FLAT CARGO CLEARANCE	,
TK(38)=0.0	, DEF=55H	FUFL TANK FLOORING	,
TK(39)=0.0	, DEF=55H	SWING TAIL/NOSE PROVISIONS	,
TK(40)=0.0	, DEF=55H	OVER WING FAIRING	,
TK(41)=0.0	, DEF=55H	WING SLOT SEAL	,
TK(42)=0.0	, DEF=55H	WING GLOVE	,
TK(43)=0.0	, DEF=55H	WINDSHIELD FAIRING AREA	,
TK(44)=0.0	, DEF=55H	BODY CONFIG. PENALTIES	(MISC WT.)
TK(45)=1.0	, DEF=55H	FUSELAGE MISC WEIGHT(STATISTICAL CORRECTION)	,
TK(51)=0.0	, DEF=55H	MLG STRUC-SINGLE WHEEL-VERT.COLUMN LAND BASED	,
TK(52)=0.0	, DEF=55H	MLG STRUC-SINGLE WHEEL-VERT.COLUMN CAR BASED	,
TK(53)=0.0	, DEF=55H	MLG STRUC-MULTIE WHEEL-VERT.COLUMN LAND BASED	,
TK(54)=1.0	, DEF=55H	MLG STRUC-SINGLE WHEEL-TRIPOD TYPE LAND BASED	,
TK(55)=0.0	, DEF=55H	MLG STRUC-SINGLE WHEEL-TRIPOD TYPE CAR BASED	,
TK(56)=1.0	, DEF=55H	MLG STRUC-BOMBERS AND FIGHTERS	LAND BASED
TK(57)=0.0	, DEF=55H	MLG STRUC-TRANSPORTS	LAND BASED
TK(58)=0.0	, DEF=55H	MLG STRUC-FIGHTER + ATTACK FUS TOW CAR BASED	,
TK(59)=0.0	, DEF=55H	MLG STRUC-FIGHTER + ATTACK NOS TOW CAR BASED	,
TK(60)=0.0	, DEF=55H	MLG ROLLING STOCK -WHEELS HIGH PRS	LAND BASED
TK(61)=1.0	, DEF=55H	MLG ROLLING STOCK -WHEELS LOW PRS	LAND BASED
TK(62)=0.0	, DEF=55H	MLG ROLLING STOCK -WHEELS HIGH PRS	LAND BASED
TK(63)=1.0	, DEF=55H	BRAKES -NO DRAG CHUTE	,
TK(64)=0.0	, DEF=55H	BRAKES - DRAG CHUTE	,
TK(65)=1.0	, DEF=55H	TIRES-TYPE III AND VII	,
TK(66)=0.0	, DEF=55H	TIRES-TYPE VIII	,
TK(67)=1.0	, DEF=55H	MLG ROLLING STOCK	,
TK(68)=1.0	, DEF=55H	LANDING GEAR CONTROLS	,
TK(69)=1.0	, DEF=55H	EXT MOUNT JET ENGINE COWLING	,
TK(81)=1.0	, DEF=55H	EXT MOUNT JET ENGINE PYLON SINGLE ENGINE INSTALLATION,	,
TK(82)=0.0	, DEF=55H	EXT MOUNT JET ENGINE PYLON SIAMSEENGINE INSTALLATION,	,
TK(83)=0.0	, DEF=55H	EXT MOUNT TURBOPROP COWLING	,
TK(84)=0.0	, DEF=55H	MAIN LANDING GEAR DOORS(JET-TURBOPROP)	,
TK(85)=0.0	, DEF=55H	NACELLES WITH COWL FLAPS (PISTON ENGINE)	,
TK(86)=0.0	, DEF=55H	NACELLES WITH AIR BAFFLES(PISTON ENGINE)	,
TK(87)=0.0	, DEF=55H	MAIN LANDING GEAR DOORS (PISTON ENGINE)	,
AF =0.0	, DEF=55H	CABIN FLOOR AREA -SQ FT	,

AGL	=0.0	WINDOW AREA, CABIN, TRANSPORTS -SQ FT.
BN	=3.0	MAXIMUM NACELLE BREATHT-FT
BODY	=40.0	FIXED BODY WEIGHT-LBS
BP	=48.5	WING SPAN ALONG 50 PC CHORD-FT
CD	=0.8	SPEED BRAKE DRAG COEFFICIENT
CE	=0.0	INLET DUCT CIRCUMFERENCE AT ENGINE-FT/DUCT
CF	=0.0	FUS CIRCUMFERENCE-FT
CI	=0.0	INLET DUCT CIRCUMFERENCE AT INLET-FT/DUCT
CL	=2.2	LIFT COEFFICIENT LANDING CONFIGURATION
CSDA	=0.0	CLAMSHELL CR AND MECH AREA-SQ FT/AP
DAF	=3.0	AFT FUS AVG VERTICAL BENDING DEPTH-FT
DC	=0.0	ULTIMATE ARRESTING HOOK DRAG COMPONENT-LB
DCK	=0.0	D SUB-C CONSTANT (MULTIPLYING CONSTANT FOR DC)
DE	=0.0	ENGINE COMPARTMENT DIAMETER-FT
DEF	=4.8	FWD FUS AVG VERTICAL BENDING DEPTH-FT
DHB	=6.0	BOMB OR MISSILE BAY WIDTH-FT
DI	=3.0	MAXIMUM NACELLE DEPTH-FT
DT	=34.8	MAXIMUM OUTSIDE DIAMETER OF MLG TIRES-INS
DWA	=3.2	AFT FUS AVG SIDE BENDING WIDTH-FT
DWF	=3.8	FWD FUS AVG SIDE BENDING WIDTH-FT
DWH	=10.0	BEAD LEDGE DIAMETER-INS
FCCDA	=0.0	FLAT CGO CLEARANCE DR, AREA-SQ FT
FH	=0.0	HORIZONTAL TAIL LOAD-LBS
FIXED	=0.0	FIXED STRUCTURE (LANDING GEAR)-LBS
FLAG	=0.0	J BODY, NAC, LG-1 BODY-2 LG-3 NAC
FTFA	=0.0	FUFL TANK FLOORING AREA-SQ FT
FV	=0.0	VERTICAL TAIL LOAD-LBS
FVM	=0.0	MAIN GEAR VERTICAL LOAD-LBS/SIDE
FVN	=0.0	NOSE VERTICAL LOAD-LBS
GF	=0.0	FUSELAGE FUEL CAPACITY (GALLONS)
HTVC	=0.7	HORIZONTAL TAIL VOLUME COEFFICIENT
IPWT(1)	=2574.1	ACTUAL WEIGHT OF BODY GROUP-LB
IPWT(2)	=1323.0	ACTUAL WEIGHT LANDING GEAR GROUP-LB
IPWT(3)	=676.0	ACTUAL WEIGHT NACELLE GROUP-LB
K	=14.6	WINDSHIELD AND CANOPY CONSTANT
KB	=19.24	BOMB BAY TYPE FACTOR
KF	=0.0	FUS FUEL TANK CONSTANT
KG	=1.5	FACTOR=1.0 NO GEAR IN NAC =1.265 GEAR IN NACELLE

KYA	=0.0	MLG STRUCTURE TYPE FACTOR-1	TRAN-0.733	BCMMERS
KMLD	=3.223	MLG DOORS	TYPE CONSTANT	
KXN	=1.33	NACELLE TYPE CONSTANT (SEE USERS GUIDE)		
KNO	=1.0	NOSE GEAR DESIGN CRITERIA-SEE MANUAL		
KPYL	=1.0	FACTOR=1 FOR MIL TRAN AND BOMB =2 COMMERCIAL		
KS	=0.067	EXTERNAL STORES CONSTANT		
LAF	=0.0	LENGTH(C/L WING BOX/ CG AFT FUEL)-FT		
LAL	=20.0	AFT LONGERON LENGTH C/L WING AFT-FT		
LB	=40.0	BRACE LENGTH- C/L TRUNNION TO DRAG BRACE FTG-INS		
LD	=0.0	INLET DUCT LENGTH (C/L DUCT)-FT/DUCT		
LE	=0.0	ENGINE COMPARTMENT LENGTH-FT		
LSPYL	=77.0	PYLON LEADING EDGE SWEEP ANGLE - DEGREES		
LEX	=72.0	MLG EXTENDED LENGTH C/L(TRUN/AXLE)-INS		
LFXN	=54.0	MLG EXTENDED LENGTH C/L(TRUN/AXLE)-INS		
LFF	=0.0	LENGTH(C/L WING BOX/ CG FWD FUEL)-FT		
LFL	=20.0	FWD LONGERON LENGTH C/L WING/ K BHD-FT		
LFLR	=0.0	CARGO FLOOR LENGTH-FT		
LGF	=0.0	LANDING GFAR FAIRING LENGTH-FT		
LHT	=21.0	LENGTH(C/L WING BOX/ C/L HT BOX)-FT		
LHr	=8.0	TOTAL BOMB OR MISSILE BAY LENGTH-FT		
LN	=10.2	NACELLE COWL LENGTH- FT		
LX	=0.0	NOT USED		
LPP	=0.0	LENGTH(C/L WING BOX/ CG ENG INSTL)-FT		
LRA	=0.0	CGO RAMP LENGTH -FT.		
LTR	=0.0	STRUT LENGTH ABOVE TRUNNION-INS		
LVT	=15.5	LENGTH(C/L WING BOX/ C/L FIN BOX)-FT		
LWS	=0.0	LENGTH OF WING SLOT-FT		
ND	=0.0	NUMBER OF INLET DUCTS		
NE	=0.0	NUMBER OF ENGINES PER AIRPLANE		
NF	=0.0	NUMBER OF FUSELAGE FUEL TANKS		
NS	=2.0	NUMBER OF MLG INSTALLATIONS PER A/P		
NL	=4.5	DESIGN LANDING ULTIMATE LOAD FACTOR		
NH	=2.0	NUMBER OF LIKE NACELLES PER AIRPLANE		
NPYL	=2.0	NUMBER OF LIKE PYLONS PER AIRPLANE		
NS	=2.0	NUMBER OF STORE STATIONS		
NS1	=0.0	NUMBER OF STORE STATIONS 1		
NS2	=0.0	NUMBER OF STORE STATIONS 2		
NSr	=2.0	NUMBER OF SPEED BRAKES		

NST	= 2.0	NUMBER OF MLG STRUTS PER AF
WT	= 3.0	TAXI LOAD FACTOR-ULTIMATE
NTI	= 2.0	NUMBER MAIN LANDING TIRES PER AIRPLANE
WHL	= 2.0	NUMBER MAIN LANDING GEAR WHEELS
NX	= 0.0	CATAPULT LOAD FACTOR (ULTIMATE)
PC	= 15.0	ULTIMATE CABIN PRESSURE
PCW	= 0.0	SFC MANUAL
PD	= 0.0	DUCT PRESSURE-PSI (COMPUTED IF BLANK)
P	= 1340.0	MAX OPERATING DYNAMIC PRESSURE-PSF
SC	= 21.1	WINDSHIELD AND CANOPY AREA-SQ FT
SJA	= 0.0	SIDE LOADING DOOR AND MECH-SQ FT
SFF	= 623.0	FUSELAGE WETTED AREA MINUS CUTOUTS-SQ FT
SEW	= 0.0	WINDSHIELD FAIRING AREA-SQ FT
SGF	= 0.0	LANDING GEAR FAIRING AREA-SQ FT
SGL	= 0.0	GLOVE SURFACE AREA-SQ FT
SW	= 15.0	MLG STROKE (INCHES)
SWR	= 0.0	MISSILE OR BOMB BAY DR., FT SQ
SMD	= 18.0	MLG DOOR AREA-SQ FT
SL	= 94.0	NACELLE COWL SURFACE AREA-FT SQ/ NAC
SND	= 11.0	MLG DOOR AREA-SQ FT
SPYL	= 10.0	PYLON PLANFORM AREA - FT SQ/ NACELLE
SRA	= 0.0	CARGO RAMP AREA-SQ FT
SSR	= 12.0	SPEED BRAKE AREA EACH-SQ FT
SW	= 400.0	WING AREA-THEO SQ FT
SWF	= 0.0	OVER WING FAIRING AREA-SQ FT
SWP	= 0.0	CARGO AND PASS COMPARTMENT WETTED AREA-SQ FT
TAILB	= 0.0	TAIL BUMPER WEIGHT-LBS
TIRWT	= 0.0	TIRE WEIGHT IF INPUT-LBS
TOT	= 0.0	THRUST PER ENGINE-LBS
TYPE	= 0.0	FLAG (0 USAF, 1 USN, 2 BOMBER, 3 TRANSPORT)
ULF	= 12.0	FLIGHT DESIGN ULTIMATE LOAD FACTOR
VC	= 16.0	COCKPIT VOLUME-CU FT
VS	= 0.0	STALL SPEED (COMPUTED IF BLANK)-FT/SFC
WAI	= 3449.0	WT AIRBODY EXCLUD.FUEL AFT C/L WING-LBS
WC	= 0.0	CATAPULT DESIGN GROSS WEIGHT-LBS
WDES	= 23545.0	DESIGN GROSS WEIGHT-LBS
WF	= 0.0	1 G DESIGN FLOOR LOADING-LBS
WEA	= 0.0	WT AIRBODY FUEL AT DESIGN CONDITION-LBS

WFF	=0.0	,DEF=55H	WT FWD BODY FUEL AT DESIGN CONDITION-LBS	,
WFL	=11.0	,DEF=55H	WHEEL WIDTH BETWEEN FLANGES-INS	,
WFI	=6950.0	,DEF=55H	WT FWD BODY EXCLUD.FUEL FWD C/L WING-LBS	,
WLAND	=28000.0	,DEF=55H	DESIGN LANDING WEIGHT-LBS	,
WMAX	=38000.0	,DEF=55H	MAXIMUM GROSS WEIGHT-LBS	,
WNC	=1686.0	,DEF=55H	WGT OF MACELLE CONTENTS-LBS	,
WPD	=0.0	,DEF=55H	WT OF ENGINE INSTALLATION-LBS	,
WS	=5000.0	,DEF=55H	DESIGN STORE WEIGHT PER STA-LBS	,
WS1	=0.0	,DEF=55H	WT AT STORE STATION 1-LBS	,
WS2	=0.0	,DEF=55H	WT AT STORE STATION 2-LBS	,
WTI	=15.0	,DEF=55H	TIRE MAXIMUM SECTION WIDTH-INS	,
WTP(1,1)	=229.0	,DEF=55H	INPUT FROM APAS - PANELS-LB	,
WTP(2,1)	=31.0	,DEF=55H	INPUT FROM APAS - LONGERONS-LB	,
WTP(3,1)	=223.0	,DEF=55H	INPUT FROM APAS - FRAMES-LB	,
WTP(4,1)	=107.0	,DEF=55H	INPUT FROM APAS - WEBS-LB	,
WTP(5,1)	=0.0	,DEF=55H	INPUT FROM APAS - NON-STRUCTURAL-LB	,
WWE	=2000.0	,DEF=55H	MAX WEAPON WT-LBS	,
END				
6 7 8 9	IN COL 1			

APPENDIX II

Test Cases

[illegible]

[illegible]

[illegible]

LANDING GEAR 880 TEST CASE

OUTPUT

VS-LANDING CONF. POWER OFF STALL SPEED KNOTS	128.48
DESIGN LOAD /1000.	555.00
DRAW BRACE RATIO	.65
KF-KINETIC ENERGY/1000 FT-LB	135444.63

WEIGHTS

MLG STRUC-SINGLE WHEEL-VERT.COLUMN LAND BASED	0.0
MLG STRUC-SINGLE WHEEL-VERT.COLUMN CARR BASED	0.0
MLG STRUC-MULTI WHEEL-VERT.COLUMN LAND BASED	2819.0
MLG STRUC-SINGLE WHEEL-TRIPOD TYPE LAND BASED	0.0
MLG STRUC-SINGLE WHEEL-TRIPOD TYPE CARR BASED	0.0
MLG STRUC-BOMBERS AND FIGHTERS LAND BASED	0.0
MLG STRUC-TRANSPORTS LAND BASED	441.0
MLG STRUC-FIGHTER + ATTACK FUS TJW CARR BASED	0.0
MLG STRUC-FIGHTER + ATTACK NOS TJW CARR BASED	0.0
MLG ROLLING STOCK -WHEELS HIGH PRS LAND BASED	518.0
MLG ROLLING STOCK -WHEELS LOW PRS LAND BASED	0.0
MLG ROLLING STOCK -WHEELS CARR BASED	0.0
BRAKES -NO DRAG CHUTE	1182.0
BRAKES -DRAG CHUTE	0.0
TIRES-TYPE III AND VII	0.0
TIRES-TYPE VIII	0.0
TIRE WT. INPUT	709.0
MLG ROLLING STOCK	149.0
LANDING GEAR CONTROLS	615.0
TAIL BUMPER WT.	6.0
FIXED STRUCTURE	191.0
 TOTAL LANDING GEAR	 6630.0
 ACTUAL WEIGHT	 6933.0
 WEIGHT FACTOR	 1.046

NACELLE WEIGHT 880 TEST CASE

JET ENGINE COWLING	1844.4
JET ENGINE PYLONS SINGLE ENGINE	1758.5
JET ENGINE PYLONS SIAMESE ENGINE	0.0
TURBOPROP COWLING	0.0
TURBOPROP MAIN LANDING GEAR DOOR	0.0
PISTON ENGINES NAC WITH COWL FLAPS	0.0
PISTON ENGINES NAC WITH AIR PLUGS	0.0
PISTON ENGINES MAIN LANDING GEAR DOORS	0.0
 TOTAL NACELLE GROUP	 3602.9
ACTUAL WEIGHT	3685.0
WEIGHT FACTOR	1.023

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HCZR-101ALS

DATE	DESCRIPTION	AMOUNT	BALANCE
1951-01-01	OPENING BALANCE	100.00	100.00
1951-01-15	PAYROLL	25.00	75.00
1951-01-30	RENT	15.00	60.00
1951-02-15	UTILITIES	10.00	50.00
1951-02-28	SALARY	30.00	20.00
1951-03-15	RENT	15.00	5.00
1951-03-31	CLOSING BALANCE		5.00

LANDING GEAR R-534 TEST CASE

OUTPUT

VS-LANDING CONF. POWER OFF STALL SPEED KNOTS	139.46
DESIGN LOAD /1000.	489.00
DRAW BRACE RATIO	.54
KE-KINETIC ENERGY/1000 FT-LB	140592.56

WEIGHTS

MLG STRUC-SINGLE WHEEL-VERT.COLUMN LAND BASED	0.0
MLG STRUC-SINGLE WHEEL-VERT.COLUMN CARR BASED	0.0
MLG STRUC-MULTI WHEEL-VERT.COLUMN LAND BASED	1588.0
MLG STRUC-SINGLE WHEEL-TRIPOD TYPE LAND BASED	0.0
MLG STRUC-SINGLE WHEEL-TRIPOD TYPE CARR BASED	0.0
NLG STRUC-BOMBERS AND FIGHTERS LAND BASED	249.0
NLG STRUC-TRANSPORTS LAND BASED	0.0
NLG STRUC-FIGHTER + ATTACK FUS TOW CARR BASED	0.0
NLG STRUC-FIGHTER + ATTACK NDS TOW CARR BASED	0.0
MLG ROLLING STOCK -WHEELS HIGH PRS LAND BASED	395.0
MLG ROLLING STOCK -WHEELS LOW PRS LAND BASED	0.0
MLG ROLLING STOCK -WHEELS CARR BASED	0.0
BRAKES -NO DRAG CHUTE	0.0
BRAKES -DRAG CHUTE	580.0
TIRES-TYPE III AND VII	0.0
TIRES-TYPE VIII	0.0
TIRE WT. INPUT	444.0
NLG ROLLING STOCK	107.0
LANDING GEAR CONTROLS	388.0
TAIL BUMPER WT.	0.0
FIXED STRUCTURE	0.0

TOTAL LANDING GEAR	3751.0
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ACTUAL WEIGHT	3412.0
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WEIGHT FACTOR	.910
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NACELLE WEIGHT R-58A TEST CASE

JET ENGINE COWLING	3539.1
JET ENGINE PYLONS SINGLE ENGINE	1037.2
JET ENGINE PYLONS SIAMESE ENGINE	0.0
TURBOFAN COWLING	0.0
TURBOFAN MAIN LANDING GEAR DOOR	0.0
PISTON ENGINES NAC WITH COWL FLAPS	0.0
PISTON ENGINES NAC WITH AIR PLUGS	0.0
PISTON ENGINES MAIN LANDING GEAR DOORS	0.0
 TOTAL NACELLE GROUP	 4576.3
ACTUAL WEIGHT	4675.0
WEIGHT FACTOR	1.022

TITLE=504 A7 TEST CASE

325

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LANDING GEAR AX TEST CASE

OUTPUT

VS-LANDING COEF. POWER OFF STALL SPEED KNOTS	112.76
DESIGN LOAD /1000.	114.00
DRAW BRACE RATIO	.62
KE-KINETIC ENERGY/1000 FT-LB	21429.73

WEIGHTS

MLG STRUC-SINGLE WHEEL-VERT.COLUMN LAND BASED	0.0
MLG STRUC-SINGLE WHEEL-VERT.COLUMN CARR BASED	0.0
MLG STRUC-MULTI WHEEL-VERT.COLUMN LAND BASED	0.0
MLG STRUC-SINGLE WHEEL-TRIPOD TYPE LAND BASED	268.0
MLG STRUC-SINGLE WHEEL-TRIPOD TYPE CARR BASED	0.0
NLG STRUC-BOMBERS AND FIGHTERS LAND BASED	110.0
NLG STRUC-TRANSPORTS LAND BASED	0.0
NLG STRUC-FIGHTER + ATTACK FUS TOW CARR BASED	0.0
NLG STRUC-FIGHTER + ATTACK NOS TOW CARR BASED	0.0
MLG ROLLING STOCK -WHEELS HIGH PRS LAND BASED	0.0
MLG ROLLING STOCK -WHEELS LOW PRS LAND BASED	177.0
MLG ROLLING STOCK -WHEELS CARR BASED	0.0
BRAKES -NO DRAG CHUTE	235.0
BRAKES -DRAG CHUTE	0.0
TIRES-TYPE III AND VII	167.0
TIRES-TYPE VIII	0.0
TIRE WT. INPUT	0.0
NLG ROLLING STOCK	74.0
LANDING GEAR CONTROLS	144.0
TAIL BUMPER WT.	0.0
FIXED STRUCTURE	0.0

TOTAL LANDING GEAR	1175.0
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ACTUAL WEIGHT	1323.0
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WEIGHT FACTOR	1.126
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NACELLE WEIGHT AX TEST CASE

JET ENGINE COWLING	428.3
JET ENGINE PYLONS SINGLE ENGINE	303.9
JET ENGINE PYLONS SIAMESE ENGINE	0.0
TURBOPROP COWLING	0.0
TURBOPROP MAIN LANDING GEAR DOOR	0.0
PISTON ENGINES NAC WITH COWL FLAPS	0.0
PISTON ENGINES NAC WITH AIR PLUGS	0.0
PISTON ENGINES MAIN LANDING GEAR DOORS	0.0
 TOTAL NACELLE GROUP	 732.2
ACTUAL WEIGHT	676.0
WEIGHT FACTOR	.923

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